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Patterns of Calcium Signaling based on HH Model

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***Abstract*— In this paper we represent the HH model. The study of HH model mechanism generates the action potential in axon and also gives mathematical equations. In this model we used different ions like Na and K but we do not considered the Ca^{2+} ion but in this paper we show how calcium channel signal is used for signaling in neuron network. Calcium channels are mostly used for providing the communication between neuron networks.**

Keywords*— Action potential, Mathematical, Calcium Channels, Communication, Neuron Network.

1. INTRODUCTION

For neuronal development there are different aspects to regulates the neuronal oscillations like neuronal migration, neuronal differentiation and connection pattern. The spontanious synchronized Ca^{2+} ions are the one type of the oscilation which are observed by neuron without using any stimulai. The result is came through excitatory synaptic transmission. [1] .There are two different type of modes of transmission. The stydy of small antibiotic gramicidin Hladky and Haydon define the existance of the different ions channels. In 1952 Hodgkin and Huxley's analyse the electric activity of the two different ions Na^{2+} and K^{2+}. They suggest that ionic pathway of the channels take 20 times more year then Hladky and Haydon define the existance of the different ions channels.[2].

First time ELF magnatic field is planned which is based on the pervation of the calcium channels in which stimulation is applied by the magnetic field. It supposed that the probability of the open changes in the opening channels in magnetic field then it increase the number of the opening channel with magnetic field.[4]. The reason behind the increment in number of opened channels may be the increment in the intra cellular calcium concentration. According to the Brownian dynamics model shows the curve against time, displacement and average velocity of calcium ions which showing the ELF magnetic field.[4,5]. The capacity of calcium channels also based on the inter celluler based wave model which is basically called calcium signaling which is used by the widespread range of the different organism with different types of cells. Calcium ion(Ca^{2+}) is most important for the calcium cellular signaling. In Ca^{2+} signaling there is a movement between intracellular and extracellular compartmant who alters the action potential. In humans we believe that the oscilation is acts as a path for the long range of signaling and information trasport in the brain.[6,7]. The inter-cellular calcium ion Ca^{2+} passing alternans free from the sarcoplasmic reticulum (SR). It shows that the inter-cellular of calcium ion (Ca^{2+}) alternans was generated through the transmitting waves of calcium ions release and continuous through the interchange of SR of Ca^{2+} content that has a hard relationship with the Ca^{2+} transient. Through this we can easly understand the Ca^{2+} alternans with out any need of refractoriness of L-type calcium ion. The effect of the Ca^{2+} is that it generate the diffusion wave concordant and dis-concordant Ca^{2+} alternans in the cell was also analyzed.[6]. In calcium signaling Ca^{2+} channels involves the VGCC, NMDA receptors, AMPA receptors, TRP channels, and depot controlled channels.

In universe calcium ion(Ca^{2+}) is second most important messenger to spread the information in tissues for the calcium signaling. When calcium waves transmits there is gap between channels which is formed by the cell membrane. To utilize the property of calcium signaling we use the model called cluster based network model. Which is commpossed of different cell and neurosensors[9]. Calcium signaling is also helpful to investigate the errors. Mean it also important for error control which is based on molecular communications[8]. Calcium signaling network consist of different nodes -

i) Receptors and Ligands,

ii) Soluble second messengers

iii) Selective/non-selective ion channels

The Ca^{2+} signaling network act as a toolkit. It is used to assembles the signals through system with very different temporal and spatial dynamics.[10].

2. HH Model

Calcium ions(Ca^{2+}) is universal signaling ion that regulates the variation of neuronal function. By binding to and modifying the state of effector protiens. Using mathematical or computational modeling we can easily understand the concept of calcium signaling.

In 1952 Alan Lloyd Hodgkin and Andrew Huxley gives the experimental sets of equation to fit the data in axon. In calcium ion channels there are two different divisions i.e. LVA(lower-voltage activation) and HVA(high-voltage activation). HVA channel found in the outside the presynaptic and owing high threshold. LVA offen called T-channels. Hodgkin and Huxley model is also known as "modeling schema" rather then model. The basic HH circuit model further more extended to gives the basic details of the physiology of the neurons. The HH model is most famous and complex model till date. The HH model is a mathematical model which is "conductance based model" which describe the action potential in neuron which are

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initiated and propogated. It is a set of nonlinear equation which describe the electrical characterstics of different neuron cells. The HH model works on three ion channels K^+(potassium), Na^+ (sodium) and leak current that consist of Cl^- ions. K^+ and Na^+ ions channels they both are used to control the flow of ion channels in cell membrane and they both are voltage dependent ion channels. And the leak current channel is mainly responsible for the inactive membrane potential. The Hodgkin and Huxley model is benificial for the squid. Squid is the large diameter of the giant axons. It benificial because it manipulates the non technical small axons which is used in the biophysical studies. In 1963 Hodgkin and Huxley model is awarded with the noble prize in Medicins and Physiology[1,3,4].-

2.1 Electrical equivalent circuit

In terms of mathematical expression, HH model based on parallel circuit having resistors, capacitor and batteries. In fig.1 capacitor is used to store the charge capacity of the cell membrane. Resistors are the various types of ion channels which are fixed in membranes and batteries represent the intracellular and extracellular ions [12].

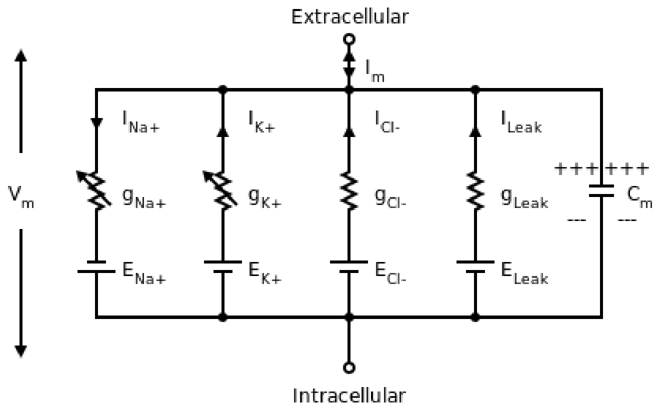

FIGURE 1. Electrical circuit of HH model

The leak current or leakage channel is determined by the voltage independent conductance.

$$g = 1/R \qquad (2.1)$$

On the other hand conductance is voltage and time dependent. These channels describe some different variables *m*, *n* and *h*. Where *m* and *h* controls by the Na^+ ions and n controls by K^+ ion channels. These variables are also called gating variables. They represented as *gNa, gK and gL.*

$$m = \alpha_m(V)(1-m) - \beta_m(V)m \qquad (2.2)$$

$$n = \alpha_n(V)(1-n) - \beta_n(V)n \qquad (2.3)$$

$$h = \alpha_h(V)(1-h) - \beta_h(V)h \qquad (2.4)$$

TABLE -1

X	E_x (mv)	g_x(ms/cm^2)
Na	55.17	1.2
K	-72.14	0.36
L	-49.42	0.003

We have some equations in which we have various function α and β to determine the empherical function of *a* determine by the Hodgkin and Huxley to fit the data in axon of the squid. E_{Na} , E_K *and* E_l these parameters are known as Reversal potentials.

TABLE -2

x	α_x
n	$0.01 * (v + 50)/(1 - exp(-(v + 50)/10))$
m	$0.1 * (v + 35)/(1 - exp(-(v + 35)/10))$
h	$0.07 * exp(0.05 * (v + 60))$

TABLE-3

x	β_x
n	$0.125 * exp(-(v + 60)/80)$
m	$4.0 * exp(-0.0556 * (v + 60))$
h	$1/(1 + exp(-(0.1) * (v + 30)))$

. Geometrically in synaptic integration neuron plays a significant role. The effect of synaptic input on membrane potential depends on the location of synapse on the dendrites tree. The result is depending on the passive dendrites which is usually necessary for the complex geometry and active ions channels.

Some authors give a best review on neuron which is related to HH model. In 1995 *Nelson and Rinzel* gives a best review of HH model in the book in which they include some historical part based on neuron. In 1987 *Cronin* discus about the monograph of Cronin using the mathematical equation of the HH model. The book of Christ of Koch in 1999 *Koch* gives the comprehensive and readable introduction of single neuron. In 1992 in *B.Hille's* book we *found* the detailed information of the ion channels and the effect of the membrane on *`Ionic channels of excitable membranes'*. In 1995 *Bower and Beeman* gives the practical guidelines related to the simulation of the single neuron model.

2. What HH model actually did?

The working of HH model consists of three stages:

1) The model assumptions:

In this the basic model consists of independent channels. These independent channels contain the gates that follow the first order of kinetics. And the currents that carried by the ions moving down electrochemically gradient. This is simple by state. But since there are many alternative models have been proposed like Integrate and Fire model, Fitzhugh-Nagumo model.

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2) Obtaining parameters for the model:

The equations of membrane potential it has to be found to fill in the different unknown parameters. There were 3 levels where details are required which had to be determined: a) the macro characteristics of channel types, b) the number of activation and inactivation gates in the channels, and c) to describe the quantitative voltage dependency of α and β for each gate in each channel.

Number of Gates:- In HH model there is a large number of microscopic ionic channels which arise from the combined effect embedded in the membrane. In transient channel it consists of two gates:- i) activation (open probability increases with depolarization) and

ii) Deactivation (open probability decreases with depolarization). During the depolarization step HH observed that the conductance change had a *sigmoid* shape, and during repolarization step conductance change had an exponent

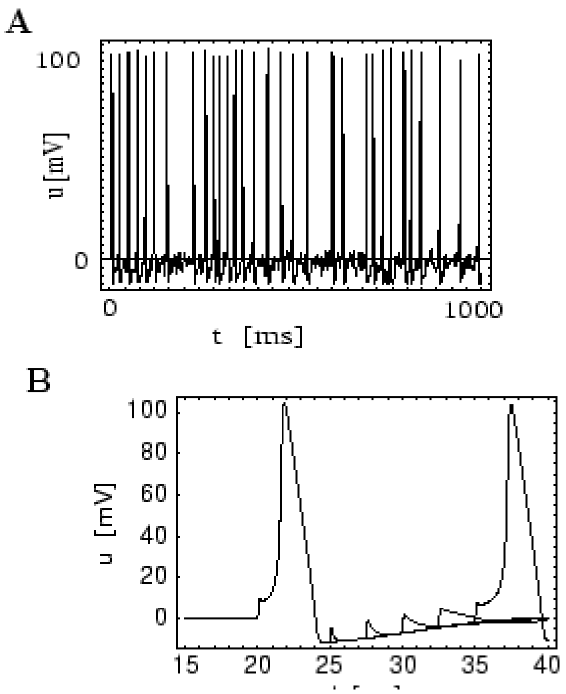

Figure 2

The properties of an excitable cell the Hodgkin and Huxley developed the four set of equations. These equations are:-

$$I = C_m \frac{dV_m}{dt} + g_k(V_m - V_k) + g_{Na}(V_m - V_{Na}) + g_t(V_m - V_l) \qquad 2.6$$

Mathematical equation for the current following through lipid biler:-

$$Ic = Cm \frac{dVm}{dT} \qquad 2.7$$

the current following through a given ion,

$$Ii = gi\,(Vm - Vi) \qquad 2.8$$

Voltage - gated ion channels,

$$I_m = C_m \frac{dV_m}{dT} + \overline{g_K} n^4(V_m - V_k) + \overline{g}_{Na} m^3 h(V_m - V_{Na}) + \overline{g}_l(V_m - V_l) \qquad 2.9$$

$$\frac{dn}{dt} = \alpha_n(V_m)(1-n) - \beta_n(V_m)n \qquad 2.10$$

$$\frac{dm}{dt} = \alpha_m(V_m)(1-m) - \beta_m(V_m)m \qquad 2.11$$

$$\frac{dh}{dt} = \alpha_h(V_m)(1-h) - \beta_h(V_m)h \qquad 2.12$$

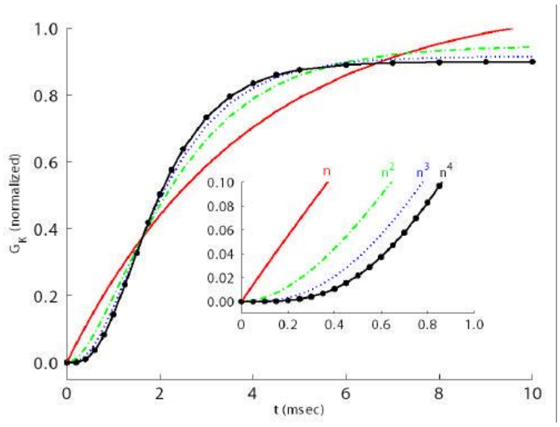

Figure 3

3) Reconstructed the spike :

The above equations describe and determined the appropriate numerical parameters by experiment. The reconstruction of the stimulus from the neuron shows the non- linearity of neuron dynamics. This model gives a numerical solution rather than the analytical one to reconstruct the stimuli. According to *M. Sarangdhar and C. Kambhampati* the analytical solution does not exist for reconstruction for retrieve the neural dynamics. [11]

3. CONCLUSION

In this paper we focused on the HH model. The HH model has been successful in describing and predicting the property of the large number of neurons. The extension of the voltage - dependent channels pair has been widely used in research area throughout the world. This model also analyzed the signal process through the sensory neurons. In this we also represent the calcium signaling process how Ca^{2+} ions regulate in the neuron. In this paper we also assumed the increase in magnetic field using calcium channels.

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