# Effect of transcranial ultrasonic-magnetic stimulation on neural spiking behaviours in Izhikevich model

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**Non-invasive brain neuromodulation are indispensable to the study of brain function. They have also proven effective for treating some neurological disorders. Transcranial ultrasonic-magnetic stimulation (TUMS), a novel method to brain neuromodulation, does not necessitate surgery or genetic alteration, but it confers spatial resolutions and depth of penetration superior to other noninvasive methods such as transcranial direct current stimulation(tDSC) and transcranial magnetic stimulation(TMS). TUMS, as study object, its numerical calculation and simulation analysis induced electric field are vitally important. Simulation analysis of current based on Izhikevich neuron model is considered in this paper. It describe how to use transcranial TUMS to modulate neural activity. The analytical results confirm that parameter values of TUMS determine the current density, different spiking behaviours are associated with the individual parameter values of TUMS. Parameter values of TUMS are crucial factors that effect interspike interval and firing rate of neural spiking activity.**

***Index Terms*—Transcranial ultrasonic-magnetic stimulation, Izhikevich model, neuron, spiking behaviours**

## I. Introduction

With the development of noninvasive brain stimulation method，such as transcranial direct current stimulation (tDSC) and transcranial magnetic stimulation(TMS) have been used to control modulation of cortical activity [1]. Lack of spatial specificity and depth of penetration impede their broad application in clinical application [2]. Transcranial ultrasonic-magnetic stimulation (TUMS) can overcome these limitations，therefore, TUMS can be applied to stimulate deep brain areas. TUMS combines the advantages of TMS with transcranial ultrasonic-magnetic stimulation (TUS). Ultrasonic waves can generate an electric field in a static magnetic field to stimulate neuron. To neuron modulation, its effects need to be researched. In previous studies, the Maxwell equation combining the ultrasound and magnetic field were provided by Norton. He obtained the distribution of electric field macroscopically [3]. Yuan Yi et al obtain the analytical solution for the voltage distribution based on the passive cable model of intracellular potential [4]. However, they did not present concrete analysis of neural spiking activity under specific numerical TUMS. Thus, we study neuron spiking behaviours induced TUMS based on Izhikevich neuron model and obtained correspondence between external current intensity and certain parameter TUMS here.

## II. Methods

In the static magnetic field, under ultrasound wave normal to it, opposite charges move to the opposite direction respectively [5]. The separated charges establish an induced current $I$ to stimulate neurons. Its current density $J$ obeys [6]:

$$J=\sigma\frac{pB}{\rho c_0}. \tag{1}$$

Here B is magnetic flux density, $\rho$ represents brain tissue density, and $c_0$ is the ultrasound speed. $p$ , $c_0$ , $\rho$ and ultrasonic power intensity $W$ obey the equation of:

$$W=\frac{p^2}{\rho c_0} \tag{2}$$

Combining (1) and (2), the following equation is obtained：

$$J=\sigma B\sqrt{\frac{W}{\rho c_0}} \tag{3}$$

The Izhikevich neuron model is presented that exhibited Hodgkin-Huxley model dynamics, yet had the computational efficiency of an integrate-and-fire neuron model [6]. In the model, a variable $v$ is used, which represent membrane potential. And the other variable $u$ represents membrane recovery variable. A spiking neuron The Izhikevich model is described by the differential equations

$$\frac{dv}{dt}=0.04v^2+5v+140\text{-}u+I \tag{4}$$

$$\frac{du}{dt}=a(bv\text{-}u) \tag{5}$$

If $v\geq+30\text{mV}$, then $v\leftarrow \text{c}$ and $u\leftarrow u+d$ .

In the above equations, v represents the membrane potential of the neuron, and $u$ is a membrane recovery variable providing negative supplying negative feedback to $v$. Synaptic current or injected current are delivered via the variable $I$ . $v$ and $u$ are reset to $c$ and $u+d$ , respectively after the spike reaches its apex (+30mV). Almost all known types of neuronal responses are simulated by tweaking the model's parameters $a$ , $b$ , $c$ and $d$ . The Izhikevich model can exhibit a discharge mode of regular spiking neurons if its parameter values are set as $a=0.02$ , $b=0.2$ , $c=-65$ and $d=6$ .

## III. Results

In this simulation, parameter values are set in $c_0=1540\text{m/s}$ , $\sigma$=0.5S/m and $\rho$=1120kg□cm$^{-2}$. TUMS was administered at different magnetic flux density $B$ , ultrasonic power intensity $W$ , ultrasonic emission cycle T and ultrasonic duty cycle D .

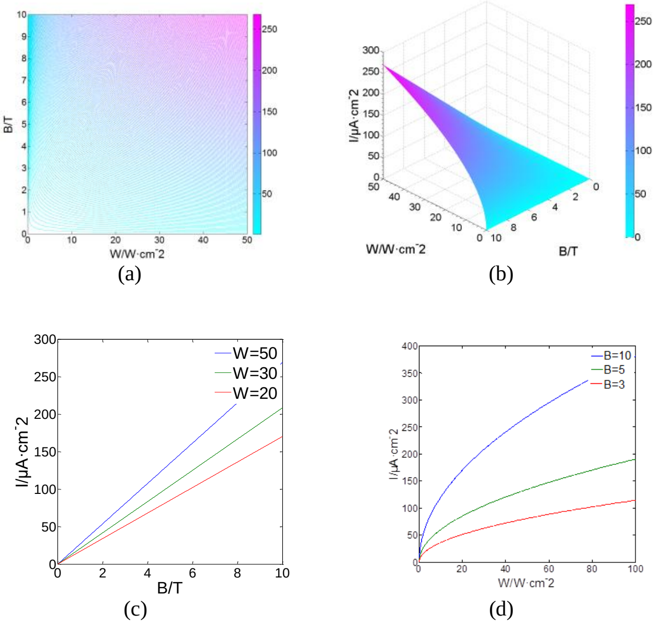


Fig. 1 (a) Contour map of current density versus magnetic flux density *B* and ultrasonic power intensity *W*. (b) Three-dimensional distribution of current density versus magnetic flux density B and ultrasonic power intensity *W*. (c) The current density of *I* versus magnetic flux density *B* at different ultrasonic power intensity *W*. (d) The current density of *I* versus ultrasonic power intensity *W* at different magnetic flux density *B*.

The current density of $I$ depend on variables $W$ and $B$ . This relation is shown in Fig. 1(a) (b). When magnetic flux density $B$ is constant, the current density curve of change is escalating slower and slower with the increase of ultrasonic power intensity $W$ . The current density is proportional to $B$ when $W$ is constant. The three-dimensional current density distribution over magnetic flux density $B$ and ultrasonic power intensity $W$ is expressed by Fig.1(c) (d).

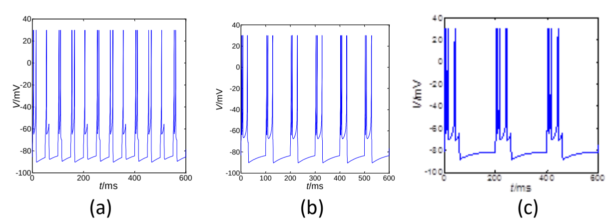


Fig. 2 Spiking train of Izhikevich model driven by the input currents of different ultrasonic duty cycle:(a) 50, (b) 100 and (c) 200ms.

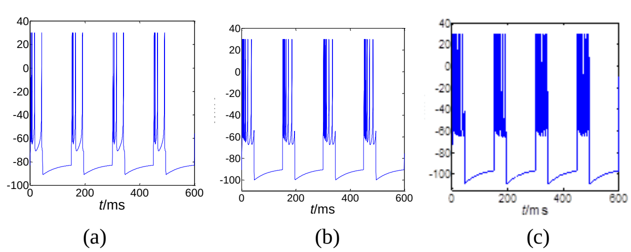


Fig. 3 Fig. 2 Spiking train of Izhikevich model driven by the input currents of different current density:(a) 15, (b) 30 and (c) 45 $\mu A/cm^2$ .

The current $I$ can provide input to an appropriately parameterized Izhikevich model to predict the spiking activity of a neuron. The spiking activity of a neuron predicted by the Izhikevich model is shown in Fig2. The cycle of input current $I$ is the same as ultrasonic emission cycle. We first examined the effect of the different ultrasonic emission cycle (50, 100 and 200ms; Fig2) on the spiking activity. We found that interspike interval is no significant change and firing rate increase with ultrasonic emission cycle. In addition, we also investigate whether the changes in interspike interval and firing rate correspond to changes in the current density of $I$ . With input different the current density （15 $\mu A/cm^2$ ，30 $\mu A/cm^2$ ，45 $\mu A/cm^2$ ）,the date is presented in Fig3. Such results indicate that interspike interval decrease and firing rate increase with increasing the current density.

## IV. CONCLUSION

We studied the effect of transcranial ultrasonic-magnetic stimulation on spiking activity of the Izhikevich neuron model. In this paper，we show how to change magnetic flux density, ultrasonic power intensity to obtain the exact current density. Furthermore, transcranial ultrasonic-magnetic stimulation is an efficient tool to effect spiking activity of neuron with setting different ultrasonic emission cycle and the current density. The TUMS described here can begin to provide a platform for the future development of Non-invasive brain neuromodulation against pervasive brain diseases and new generations of neuron spike sequences control strategies. However, non-linear dynamical behavior of neuron is not yet analyzed here. Non-linear dynamical behavior studies under TUSM are planned. Further experience in large quantities of animal is also needed to clarify the role and utility of TUMS in clinical.

## V. ACKNOWLEDGMENTS


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