

Performance and evaluation of Two-Coupled Biological Hindmarsh–Rose Neuron Model for Digital Multiplierless Realization

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Abstract- Neural Network with perforation methodology has begun as a promising solution for Digital application in VLSI Technology. This short-term work suggests improved biological Hindmarsh–Rose (HR) neuron model that is more appropriate for efficient implementation on digital platforms. Simulation results show that the model can replicate the desired performances of the neuron. The proposed model is examined, in terms of digital implementation possibility and cost, targeting a low-cost hardware implementation. Hardware implementation on a field-programmable gate array shows that the improved model mimics the biological behavior of dissimilar types of neurons, with higher performance and noticeably lowers hardware overhead cost compared with the original HR model.

Index Terms- Field-Programmable Gate Array (FPGA), Spiking Neural Network (SNN), Hindmarsh–Rose (HR) Neuron Model.

I. INTRODUCTION

The time period neural network became historically used to discuss with a network or circuit of organic neurons. The modern-day usage of the term regularly refers to artificial neural networks, which can be composed of synthetic neurons or nodes. Thus the term has two wonderful usages like Biological neural networks are made from real organic neurons that are linked or functionally associated inside the peripheral concerned system or the critical issue machine. In the sector of neuroscience, they're regularly identified as organizations of neurons that perform a particular physiological feature in laboratory analysis. Artificial neural networks are made of interconnecting synthetic neurons (programming constructs that mimic the properties of biological neurons). Artificial neural networks may also either be used to advantage a real biological neural networks, or for fixing artificial intelligence issues without always developing a model of a real organic device. The actual, organic anxious device is distinctly complicated and includes

some features that may seem superfluous primarily based on an knowledge of artificial networks.

The brain, neural networks and computer systems like neural networks, as utilized in artificial intelligence, have historically been considered as simplified fashions of neural processing inside the mind, despite the fact that the relation between this model and mind organic structure is debated, as little is known about how the brain surely works. A problem of present day studies in theoretical neuroscience is the query surrounding the diploma of complexity and the houses that character neural factors ought to have to reproduce something such as animal intelligence.

Historically, computer systems developed from the von Neumann structure, that's primarily based on sequential processing and execution of express commands. On the opposite hand, the origins of neural networks are based totally on efforts to model records processing in organic systems, which may additionally depend largely on parallel processing in addition to implicit instructions primarily based on popularity of patterns of 'sensory' access from outside assets. In different words, at its heart a neural network is a complex statistical processor (in preference to being tasked to sequentially procedure and execute). Neural coding is worried with how sensory and different information is represented within the brain through neurons. The principal goal of analyzing neural coding is to represent the dating among the stimulus and the man or woman or ensemble neuronal responses and the relationship among electric pastime of the neurons inside the ensemble. It is concept that neurons can encode each digital and analog data.

Neural networks and synthetic intelligence: A neural network (NN), inside the case of synthetic neurons referred to as synthetic neural network

(ANN) or simulated neural network (SNN), is an interconnected group of natural or artificial neurons that uses a mathematical or computational model for records processing primarily based on a connectionist technique to computation. In maximum instances an ANN is an adaptive device that modifications its shape based totally on external or inner records that flows thru the network. In more practical terms neural networks are non-linear statistical data modeling or decision making tools. They can be used to model complex relationships between inputs and outputs or to find patterns in data. However, the paradigm of neural networks - i.e., implicit, not explicit, learning is stressed - seems more to correspond to some kind of natural intelligence than to the traditional Artificial Intelligence, which would stress, instead, rule-based learning.

II. RELATED WORKS

A biological neuron is a dynamical system that produces dynamical behaviors, which can be described by a set of differential equations [13]–[22]. Several biological neuron models have been reported. The most successful and widely used neuron model, the Hodgkin–Huxley (HH) model [23], has been described. The ionic mechanism and electrical current on the membrane surface are taken into consideration in this model. After that, the FitzHugh–Nagumo (FHN) neuron model, which is the simplified version of the HH neuron model, was proposed [24]. The Morris–Lecar neuron model is a conductance-based model, and it was proposed [25] in order to describe oscillations in barnacle giant muscle fiber and is thus biologically significant. The Hindmarsh–Rose (HR) neuron model [26] displays several neuronal behaviors and an accurate output-frequency-to-input-current relationship.

Although digital computation consumes more silicon area and power per function in comparison with an analog realization, its development time is considerably lower and is robust against power supply fluctuations and thermal noise. The main objective of this brief is to achieve a low hardware overhead and a highly efficient realization of two coupled neurons for use in major neural networks as a main block. This brief presents a significantly simplified implementation of the HR neuron model.

III. SUGGESTED SYSTEM

HR piecewise linear model: In this section, the proposed modification to the original model is presented. The main motivation for these modifications is the implementation cost of the modified design. The membrane potential equation of the HR model can be rewritten, Where $a=1.394$, $b=0.189$, $c=1.40$, $d=1.42$, and m_i , $0 < i < 4$ are the slopes of lines in the PWL approximation of the $p(x)$ function. Fig 1 illustrates the matching accuracy between the original HR and HR piecewise linear (HRPWL) neuron models. Fig.1(b) shows that the $g(x)$ can be approximated by five PWL segments (shown with red dotted lines), representing linear and nonlinear terms in the equation. The mean absolute error (MAE) is another useful measure widely used in model evaluations. Also, MAE measures how far away predicted values are from observed values and is one of a number of ways to compare forecasts with their eventual outcomes [19]. MAE is a linear score, which means that all the individual differences are weighted equally on the average. As the name suggests, MAE is an average of the absolute errors $|e_i| = |x_{propi} - x_{origi}|$, where x_{propi} is the prediction and x_{origi} is the true value. In this brief, MAE is given by

$$MAE = \frac{1}{n} \sum_{i=1}^n |e_i| \dots\dots\dots(1)$$

Synaptic coupling model: In this section, the dynamical behaviors of two coupled HR neurons are presented. Accordingly, we can see the various dynamical behaviors as the current stimulus of the presynaptic neuron, the parameter r that controls the spiking frequency, and the conductance coefficient of the synaptic terminal are varied. The synaptic terminal acts as an active gate, and when the presynaptic voltage level reaches its threshold value, voltage transmission can occur. This state depends on the input stimulus, the coupling of the neurons with the same potentials ($x_{pre} = x_{post}$), and when two coupled neurons are synchronized. As mentioned previously, the synchronization effects of coupled neurons are significant for the processing of biological signals and play significant roles in the elucidation of diseases, such as Parkinson’s disease, essential tremor, and epilepsy. Consequently, by the appropriate selection of the input current stimulus and synaptic conductance coefficient, the synchronization effects can be controlled.

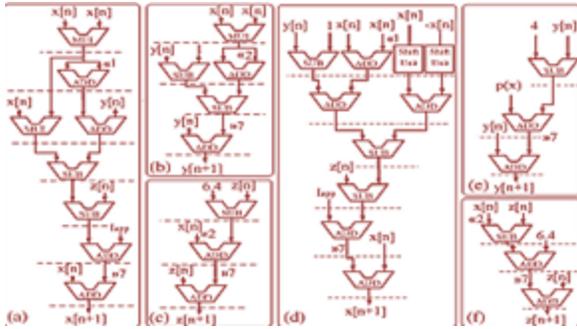


Fig. 1. Scheduling diagram of the original and proposed models. (a) Membranepotential x of the original model. (b) Recovery variable y of the original model.(c) Bursting variable z of the original model. (d) Membrane potential x of the proposed model. (e) Recovery variable y of the proposed model. (f) Bursting variable z of the proposed model.

IV DESIGN AND HARDWARE IMPLEMENTATION

This section presents the hardware implementation structure for the proposed model. In order to obtain an improved comparison in the number of used multipliers between the original and proposed models, As the first step, it is necessary to discretize equations for both models; therefore, we utilize the Euler method. The second step is the bit-width determination of the hardware functional units. The span of the membrane potential is -2 to $2V$, and the minimum bits for implementing the membrane potentials are $3b$. In the bitwidth determination, if the maximum logic shifts to the right or left are not considered, then overflow can occur. To avoid any overflow and also increasing accuracy of the calculations, a bit width of 20 that consists of $8b$ for the integer part and $12b$ for the fraction is considered.

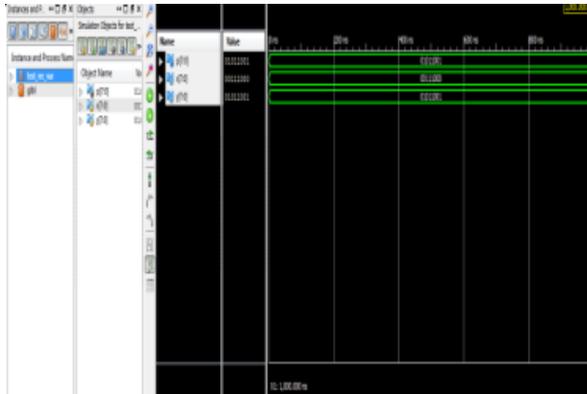


Fig.2. Simulation result for the existing recovery variable.



Fig.3. Simulation result for the proposed recovery variable.



Fig. 4. Simulation result for the existing bursting variable.

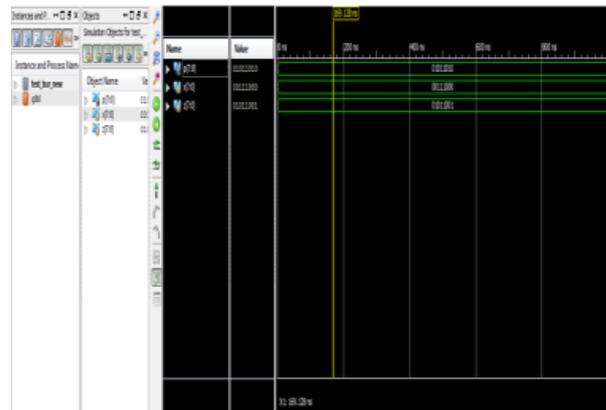


Fig. 5. Simulation result for the proposed bursting variable.

V. CONCLUSION

A multiplierless model based on the Perforation targeting low cost digital implementation has been presented. Simulation results and hardware realization show that the proposed model has acceptable error and is suitable for digital implementation. This proposed model has lower computational and hardware costs compared

with the original neuron model. This system is conveniently implemented on FPGA. This hardware is used to demonstrate different dynamics of the HR neuron model, depending on the parameter values and current stimulus, producing different patterns of spiking activity with minimal computational error.

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