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VHDL implementation of Neuron based classification for future artificial intelligence applications

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***Abstract*— An Artificial Neural Network, often just called a neural network, is a mathematical model inspired by biological neural networks. A neural network consists of an interconnected group of artificial Neurons. An artificial neuron Conceived as a crude model, or abstraction of biological neurons. This paper describes a system realization of translating data from electrochemical sensor for neuron to process on FPGA. The structure of a neuron is split into various sub blocks and these blocks will be implemented individually first and then they are integrated to form the entire neuron[1]. This paper will be implemented in three stages. First we have to convert the analog signal coming from the electrochemical sensor using an ADC (analog to digital converter). In this project the 10 bit ADC chip will be used to convert analog signal from electrochemical sensor to digital. The next module is the design of mathematical operation. This includes issues relating to data structure, design of Multiplier Accumulator (MAC) and activation function implementation. The final module is displaying the result from the data that have been accumulated by the neuron.**

Tools & H/W used: Xilinx ISE[2], MODELSIM, CHIPSCOPE, SPARTAN 3E FPGA

***Index Terms*— Neuron, ADC, MAC, FPGA**

I. INTRODUCTION

1. Artificial Neuron

The human nervous system has been treated by numerous studies. Not only from a medical point of view, as treatment for prevention of diseases, but also, from a technological point of view, trying to emulate the behavior of the biological neuron. And based on this, modeling an artificial neuron can be used to develop future applications in computational neuroscience, as well as in artificial intelligence. Artificial neural networks simplify the behavior of the human brain so, their applications are used in different fields as industrial automation, medicinal applications, robotics, electronics, security, transport, military, etc. Applications in pattern recognition like recognition of fingerprints or control of missiles use systems based on neural networks among other techniques. The following research is based exactly in this issue, to understand the real behavior of a biological neuron and according to this being able to model an artificial neuron that works in a similar way. When this artificial neuron will be developed, it will be used in future applications through complete neural networks for applications as commented previously. A neuron can be compared to a black box composed of few inputs and an output. Like an electrical circuit that makes the addition of the different signals that receives from other units and obtain in the output according to the result of the addition with relation to the threshold. The artificial neuron is an electronic device that responds to electrical signals[3].

1.1 Biological neuron

For a better understanding of how an artificial neuron works, we shall first take a look at the basic biological characteristics of a neural cell and the way this cell interconnects with other neural cells into a neural system. A neuron is a basic cell of the neural system. Estimations show that a human being possesses 1011 neural cells or neurons, which are interconnected and form around 1015 connections. Every connection has its own weight function, which is changing during the learning process. Neurons perform communication functions in a living organism.

Dendrites receive signals from other neurons in the places of connection, called the synapses. From there, the signals travel to the cell body where all the signals are approximated. If the approximation of a short interval is big enough, the cell generates the impulse, which is alongside the axon and synaptic connections transmitted to the dendrites of the neighboring neurons. This is a rather rough description of a biological neuron that seems to be simple; however, there lies a complex electrochemical system in its implementation. The brain is a collection of about 10 billion interconnected neurons. Each neuron is a cell that uses biochemical reactions to receive process and transmit information.

Biological Neuron Background

A neuron has a roughly spherical cell body called soma. The signals generated in soma are transmitted to other neurons through an extension on the cell body called axon or nerve fibers. Another kind of extensions around the cell body like bushy tree is the dendrites, which are responsible from receiving the incoming signals generated by other neurons. Typical Neuron has an axon having a length varying from a fraction of a millimeter to a meter in human body, prolongs from the cell body at the point called axon hillock. At the other end, the axon is separated into several branches, at the very end of which the axon enlarges and forms terminal buttons. Terminal buttons are placed in special structures called the synapses which are the junctions transmitting signals from one neuron to another. A neuron typically drives 103 to 104 synaptic junctions[3].

The synaptic vesicles holding several thousands of molecules of chemical transmitters, take place in terminal buttons. When a nerve impulse arrives at the synapse, some of these chemical transmitters are discharged into synaptic cleft, which is the narrow gap between the terminal button of the neuron transmitting the signal and the membrane of the neuron receiving it. In general the synapses take place between an axon branch of a neuron and the dendrite of another one. Although it is not very common, synapses may also take place between two axons or two dendrites of different cells or between an axon and a cell body. The synapse Neurons are covered with a semi-permeable membrane, with only 5 nanometer thickness. The membrane is able to selectively absorb and reject ions in the intra cellular fluid. The membrane basically acts as an ion pump to maintain a different ion concentration between the intracellular fluid and extra cellular fluid. While the sodium ions are continually removed from the intracellular fluid to extra cellular fluid, the potassium ions are absorbed from the extra cellular fluid in order to maintain an equilibrium condition. Due to the difference in the ion concentrations inside and outside, the cell membrane become polarized. In equilibrium the interior of the cell is observed to be 70 mille volts negative with respect to the outside of the cell. The mentioned potential is called the resting potential.

A neuron receives inputs from a large number of neurons via its synaptic connections. Nerve signals arriving at the pre synaptic cell membrane cause chemical transmitters to be released in to the synaptic cleft. These chemical transmitters diffuse across the gap and join to the postsynaptic membrane of the receptor site. The membrane of the postsynaptic cell gathers the chemical transmitters. This causes either a decrease or an increase in the soma potential, called graded potential, depending on the type of the chemicals released in to the synaptic cleft. The kind of synapses encouraging depolarization is called excitatory and the others discouraging it are called synapses. If the decrease in the polarization is adequate to exceed a threshold then the post-synaptic neuron fibers[3].

The arrival of impulses to excitatory synapses adds to the depolarization of soma while inhibitory effect tends to cancel out the depolarizing effect of excitatory impulse. In general, although the depolarization due to a single synapse is not enough to fire the neuron, if some other areas of the membrane are depolarized at the same time by the arrival of nerve impulses through other synapses, it may be adequate to exceed the threshold and fire.

2. Mathematical model of an artificial neuron

The common Mathematical model of an artificial neuron is shown in Fig. (1)

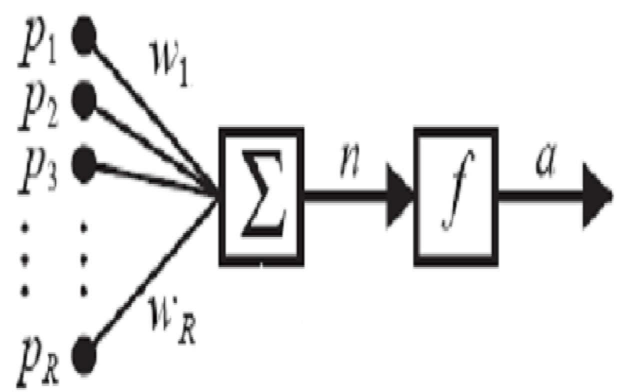

Fig.(1) Mathematical model of artificial neuron.

The neuron output can be written as:

Where P1, P2,…PR are the input vectors and W1,W2,…..WR are the weighting factors. Each input has particular weight value are summed and produce an output function f. Where a is the output function of the neuron.

$$a = f\left(\sum_{j=1}^{R} w_j p_j\right)$$

Where Pj is the input value and Wj is the corresponding weight value, a is the output of the neuron and function of f is a nonlinear activation function[4]. Typically the activation function is chosen by the designer for specific training algorithm , and then the weights will be adjusted by some learning rule so that the neuron input / output relationship meet some specific goal .

II. PROPOSED DESIGN

Implementation:

The design of an artificial neuron consists of four inputs. The artificial neuron which we are designing in our project is a prototype of the biological neuron. The Design of artificial neuron architecture on reconfigurable devices such as fpga to study the behavior of the Biological neuron. Basically a neuron consists of N inputs coming from dendrites get multiplied by the synaptic weights and then they are processed by soma. Depending on the strength of the input signals the neuron gets activated. Similarly we are going to implement an artificial neuron with 4 inputs.

The Inputs are provided by an analog circuitry which has four channels. This analog circuitry can provide the Analog voltages for 4 channels. This acts as input source for our artificial neuron. Since our FPGA cannot deal with the analog voltages, we convert the analog input into digital output. For this purpose we are going to 2 ADC modules in our project. The block diagram shown in below Fig(2).The accumulator unit is composed of a bit-serial adder and 16 bit register. The design of multiplier accumulator consists of adder and multiplier. MAC is frequently used in general computing and are especially critical to performance of digital signal processing applications[4]. The MAC typically operates on a digital, and usually binary, multiplier quantity and a corresponding digital multiplicand quantity and generates a binary product. The design of multiplier accumulator proposed in this project consists of adder and multiplier that can accommodate or handle 4 channel of input (array of sensor)[5].

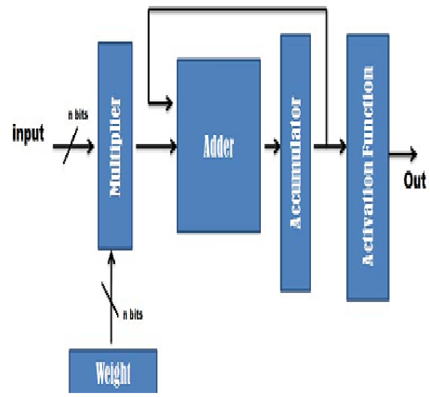

Fig (2): Block Diagram of the proposed Solution

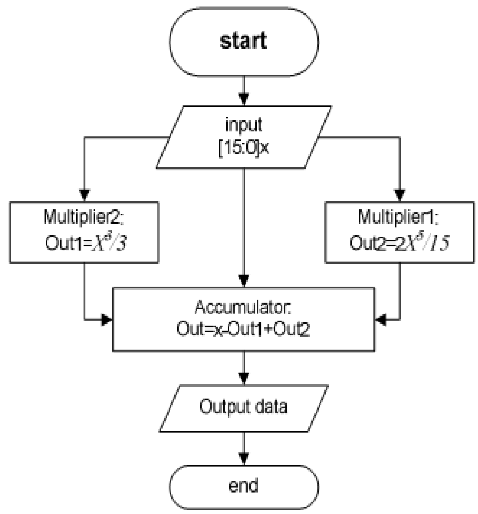

Fig (3): Design flow of Neuron Activation

Activation function in a back propagation network defines the way to obtain output of a neuron given the collective input from source synapses. The back propagation algorithm requires the activation function to be continuous and differentiable. It is desirable to have an activation function with its derivative easy to compute. The mathematical algorithm for than approximation using Taylor's Series[6][7] expansion that is used in the hardware calculation is provided by equation 2 the design flow is presented in Fig (3).

$$y = x - x^3/3 + 2x^5/15 + \ldots$$

ADC:

The Analog to Digital Module Converter Board (the AD1™) converts signals at a maximum sampling rate of one million samples per second, fast enough for the most demanding audio applications. The AD1 uses a 6-pin header connector, and at less than one square inch is small enough to be located at the signal source.

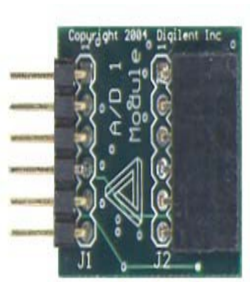

Fig (4): ADC MODULE

Implementation of ADC Module:

As we know that the analog to digital converter is used to convert the analog signal into the digital samples. And we are using the 12 bit A/D converter means at the ADC output we get the 12 bit sample values of the analog signal. Here we are giving a message signal (Modulating signal) through ADC. It is 2-channel ADC means we can give 2 inputs at a time and here we are connecting the input to the ADC from the Function Generator by giving the frequency levels and selecting a wave(sine or sawtooth, Square..Etc) and constant voltage levels.

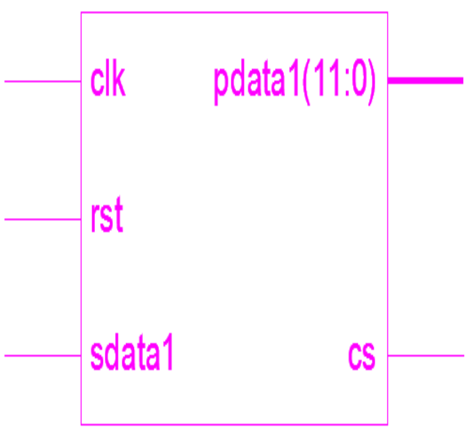

Fig (5): ADC Module LOGIC Symbol

III. RESULTS AND DISCUSSION

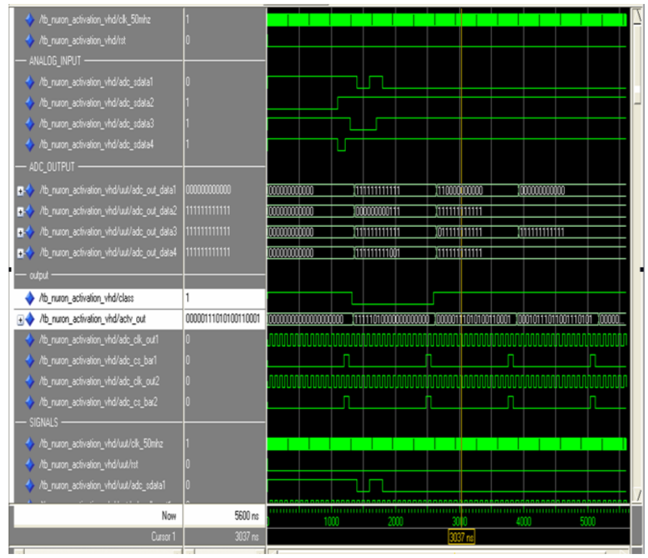

Fig (6): Top Module Simulation Result.

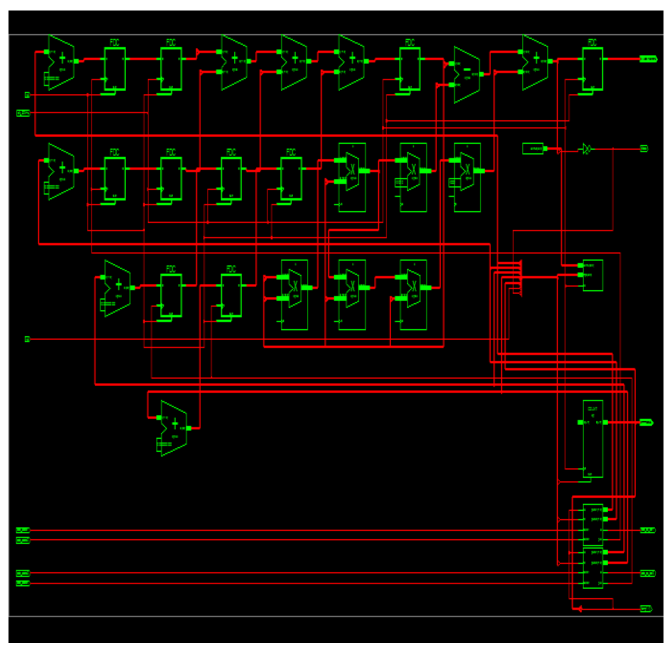

Fig (7): RTL Schematic of TOP Module

Chip scope results:

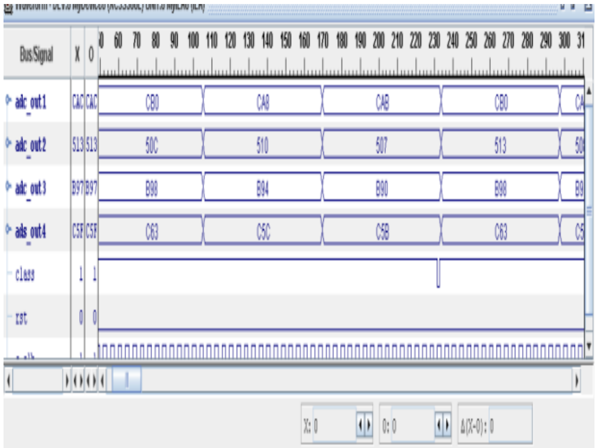

Fig (8): Chip scope Result of ADC

IV. CONCLUSIONS

The work demonstrates that the performance of artificial neuron architecture on FPGA depend strongly on the methodology, coding styles and also type of MAC ADC's used. A biological neuron with their dendrites, soma and axon can be characterized in an artificial neuron as a black box with inputs and an output. To implement the system the electronic pulses or spikes transmitted through neurons are replaced by digital signals or pulses. With all these things we get an electronic system that reproduces the behavior of the biological neuron.

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