Design & Implementation of a General Propose Neuro-Fuzzy Controller using New Current-Mode CMOS Circuits

Muhammadamin Daneshwar, Sadeq aminifar, Ghader Yosefi

Abstract—This paper presents a new general purpose neuro-fuzzy controller to realize adaptive-network-based fuzzy inference system (ANFIS) architecture. ANFIS which tunes the fuzzy inference system with a back propagation algorithm based on collection of input-output data makes fuzzy system to learn. This training is given from a standard response of the system and membership functions are suitably modified. We proposed new and improved integrated Circuits which consist of Fuzzifier, Min operator and Multiplier. Digital output realization of the circuit with 7 bit resolution makes the design programmable and extendable. However, low-voltage operation, low power dissipation, high speed as well as full compatibility with digital technologies can be achieved through the use of current-mode design techniques. Simulations based on a 0.35-µm standard technology, which are in excellent agreement with the theoretical results, are also given.

Keywords—Membership Function, Current-Mode, Layer.

I. INTRODUCTION

FUZZY systems and neural networks have attracted the interest of researchers in various scientific and engineering areas [1, 2]. The number and variety of applications of fuzzy logic and neural networks have been increasing, ranging from consumer products [3, 4] and industrial process control [5] to medical instrumentation [6,7], information systems [8] and decision analysis [9]. The main idea of fuzzy logic control (FLC) is to build a model of a human control expert who is capable of controlling the plant without thinking in terms of a mathematical model. The control expert specifies his control actions in the form of linguistic rules. These control rules are translated into the framework of fuzzy set theory providing a calculus which can simulate the behavior of the control expert.

Neural networks offer the possibility of solving the problem of tuning. Although a neural network is able to learn from the given data, the trained neural network is generally understood as a black box. Neither it is possible to extract structural information from the trained neural network nor can we integrate special information into the neural network in order to simplify the learning procedure. On the other hand, a fuzzy logic controller is designed to work with the structured knowledge in the form of rules and nearly everything in the fuzzy system remains highly transparent and easily interpretable. However, there exists no formal framework for the choice of various design parameters and optimization of these parameters generally is done by trial and error.

A combination of neural networks and fuzzy logic offers the possibility of solving tuning problems and design difficulties of fuzzy logic [10]. The resulting network will be more transparent and can be easily recognized in the form of fuzzy logic control rules or antics [11]. This new approach combines the well established advantages of both the methods and avoids the drawbacks of both. In this paper, a neuro-fuzzy controller architecture is proposed, which is an improvement over the existing neuro fuzzy controllers.

Artificial neural networks started when McCulloch and Pitts in 1943 developed their model of an elementary computing neuron and when Hebb in 1949 introduced his learning rules. A decade later Rosenblatt introduced the perceptron concept. In the early sixties Widrow and Holf developed intelligent systems such as ADALINE and MADALINE. The publication of the Mynsky and Paper in 1969 published the book with some discouraging results, that stopped the fascination of artificial neural networks for some time, and even achievements in the mathematical foundation of the back propagation algorithm by Werbos in 1974 went unnoticed. The current rapid growth of the neural network area started in 1982 with Hopfield recurrent network and Kohonen unsupervised training algorithms. The backpropagation algorithm described by Rumelhard in 1986 caused rapid development of neural networks. [12]

Artificial Neural Networks (ANNs) enjoy some distinguished characteristics and are composed of simple elements operating in parallel and including the ability to learn from data, to generalize patterns in data, and to model nonlinear relationships.

For analyzing, ANFIS architecture let us consider the summery of ANNs structure. They are computing systems based on an analogy with the work of the nervous system of the brain, in which connections organize neurons into the
networks. Therefore they are combination of mathematical functions considering neurons. Because of neuron interconnections and using kind of mathematical functions, there are different structures for various applications, in which feed forward ANNs are much more usual than another ways. The ANNs learns from samples of ANFIS uses a hybrid learning algorithm to identify parameters of Sugeno-type (FIS). It applies a combination of the least-squares method and the back propagation gradient descent method for training FIS membership function parameters, to emulate a given training data set. In other words to start ANFIS learning, first a training data set is required that contains desired input/output data pairs of the target system to be modeled.

Among the various inference methods reported in the literature, the singleton or zero-order Takagi–Sugeno–Kang’s (TSK) method is very adequate for hardware implementations. Functionally, the adaptive-network-based fuzzy inference system (ANFIS) architecture is equivalent to a TSK zero order and/or first order fuzzy system [13]. In Ref. [14], ANFIS architecture is discussed and optimized using a new algorithm. This algorithm is suited to use in CMOS circuits.

II. PROPOSED FUZZY LOGIC CONTROLLER

Functionally the ANFIS architecture is the major training routine equivalent to Taki-Sugeno first order fuzzy inference systems (FIS) [15]. ANFIS uses a hybrid learning algorithm to identify parameters of Sugeno-type FIS. It applies a combination of the least-squares method and the back propagation gradient descent method for training FIS membership function parameters, to emulate a given training data set. In other words to start ANFIS learning, first a training data set is required that contains desired input/output data pairs of the target system to be modeled. The ANFIS structure used to implement fuzzy controller with five layers is shown in Figure 1. It consists of two inputs, four membership functions for each input, sixteen fuzzy rules and one output. The ANFIS applies fuzzy inference techniques to data modeling. According to this structure, the shape of the membership functions depends on parameters, so changing these parameters will change the shape of the membership functions. The benefit of this method is that it chooses the membership function parameters automatically, that’s better than just monitoring the data and estimates these parameters.

![Fig. 1 ANFIS architecture of fuzzy controller model](image)

![Fig. 2 Membership function circuit.](image)

A. CMOS Membership Function Circuit (Layer 1, 2)

Triangular waveform and Gaussian waveform are both the usual membership functions. However, Gaussian shape membership function can obtain smoother transient response and facilitate the analog implementations. It is hard to implement the exact Gaussian shape membership function with CMOS circuit, as shown in Eq. (1).

$$
\mu(x) = e^{-(x-c)^2/2\sigma^2}
$$

(1)

Where c is the mean of the Gaussian curve and \( \sigma \) is the breadth. The use of fuzzy logic in adaptive systems has been reported in recent literature [6]. However, most of them are based on complex algorithms, with very silicon area intensive requirements for its hardware implementation. Figure 2 shows the membership function circuit, which establishes the relative distance with respect to a reference voltage for each given input.

$$
ID8 = ID7 = ID6 - (ID4 - ID2)
$$

(2)
\[ ID_3 = ID_4, ID_3 = ID_1 + ID_5 \]  
\[ ID_1 + ID_2 = ID_5 + ID_6 = 1 \]  
\[ ID_8 = 2(ID_2 - ID_5) \]

Eq. (6) and (7), show that the mismatches between M2 and M5, \( I_1 \) and \( I_2 \) will make the Gaussian waveform asymmetric.

This circuit generates two pairs of differential currents, which produce the fuzzy output current, shown in Figure.3, when they are added. That output current is mirrored into the next stage, which is a minimum detector.

**B. Max Operator (layer 3)**

Our used connective for compounding antecedents is “OR” operator which implemented using improved Max circuit from [4, 9, 11]. The output of a fuzzy control engine is a fuzzy set which represents the possible distribution of control action.

Fig. 3 shows the main idea to implement Max circuit which is based on a simple current mirror and transistor \( M_{x1} \) to provide extra current of \((I_1 - I_2)\) [15]. The drawback of this circuit is the unequal voltage of node A and B when \( M_{x1} \) turns on, because:

\[ V_A = V_{DC1} = V_{DC2} + V_T + \Delta V \Rightarrow \]
\[ V_{DC1} - V_{DC2} = V_T + \Delta V \]

This difference between node A and B causes to have an error in output reflecting. Therefore, without using any complexity, we can improve this circuit by adding \( M_{11} \) and \( M_{33} \) to solve the problem and increase output resistance. Another proposed circuit to implement max operator, is shown in right left of Fig.3. This structure is based on using Wilson current mirror and two NMOS transistors for providing extra currents of \((I_1 - I_2 \ or \ I_2 - I_1)\) which it reflects the maximum currents of \( I_1 \) or \( I_2 \) in any condition of input currents

\[ I_1 > I_2 \ or \ I_2 > I_1 \]

Even though the mentioned proposed Min and Max circuits are simple, they have high DC current rang, high accuracy and low devices.
D. Current-Mode A/D

We proposed an improved circuit based on successive approximation technique that provides a current mode A/D converter with 7bit resolution accuracy. According to the Fig. 4, two currents of $I_{in}$ (defuzzifier output) and $I_{REF}$ are applied to the MSB cell; And compared together and then digital outputs defined. Our proposed employed continues time algorithm data converter whose bit cells are better than others previously reported. Their works [6, 8] was based on that the reference current ($I_{REF}$) and the residue quantity was half continuously and mirrored constant in the other cells respectively. Because of these and decreasing current in other cells, however it causes to decrease speed and encounter error, but increases hardware and complexity. In contrast to their works, our circuit with mentioned working has capable to have low area, high speed and accuracy with 7bit resolution.

![Fig. 5 The MSB cell circuit of current mode A/D converter](image)

### III. SYSTEM SIMULATION

The proposed chip architecture designed and implemented using Hspice software. Implementation will be based on the specifications obtained from the modeling.

Depending on simulation data the structure optimized for High reconfigurability and controllability, improved scalability and sampling. However to achieve best performance, Implementation and analysis of the implemented parts with FPGA will be practiced in real conditions.

![Fig. 6 Generating of Gaussian Membership Functions from fuzzifier circuit by changing V1,V2](image)

![Fig. 7 Simulation of maximum circuit](image)

![Fig. 8 Simulation of analog multiplier](image)

![Fig. 9 Input and reference currents in range 16uA, ramped and fixed shapes, respectively](image)
IV. CONCLUSION

Proposed in this paper contains using Anfis architecture to implement programmable fuzzy logic controller chip. It consists of new Fuzzifier and Max operator circuits and improved Multiplier/Divider to implement fuzzy controller. Digital output realization of the circuit with 7 bit resolution makes the design programmable and extendable. The simulation results in 0.35um standard technology verify the performance of the proposed controller.

APPENDIX

The authors would like to thank Sama technical and vocational training, Islamic Azad University, Mahabad Branch for funding this research.

REFERENCES