

## GENERATION OF TANGENT HYPERBOLIC SIGMOID FUNCTION FOR MICROCONTROLLER BASED DIGITAL IMPLEMENTATIONS OF NEURAL NETWORKS

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**Abstract :** Standard microcontroller based neural network realizations are cheaper than application specific neural chips. For many applications standard microcontroller based neural realizations have enough performance. The main disadvantage of the microcontrollers are caused by non enough embedded mathematical operators. Especially tangent hyperbolic sigmoid and logarithmic sigmoid functions can not be realized easily on standard microcontrollers. In this paper a Taylor series expansion based method is proposed and applied on Atmel 89C51 microcontroller to realize tangent hyperbolic sigmoid function. The method and application results are shown and concluded.

**Keywords:** Neural Networks Hardware, Microcontroller, Tangent Hyperbolic Sigmoid.

### 1. INTRODUCTION

One of the most important part of a neuron is its activation function. The nonlinearity of the activation function makes it possible to approximate any function [1]. In the hardware implementation concept of neural networks, it is not so easy to realize sigmoid activation functions[1,2,3]. General hardware implementations of neural networks are the application specific integrated circuits (ASIC) [2]. There are some general purpose integrated circuits however they are limited in operation and expensive to use [1]. The application specific neural chips and general purpose ones are more expensive than a microcontroller. Usage of a microcontroller to realize a neural network has program dependent flexibility with cheapest hardware solution. The main problem of a general purpose cheap microcontroller to realize a neural network is absence of complex mathematical hardware. Existence of more complicated mathematical processing unit increases cost of the design. A flexible and software dependent method is required to realize complicated activation functions on microcontrollers.

In [4,5,6,7,8,9] analog integrated circuits were designed for function approximation. In [4,8,9] Taylor series expansion were used for analog integrated circuits with first five terms.

In this paper a Taylor series based method was implemented in digital environment. First seven terms of Taylor series expansion were used. A cheap and standard Atmel 89C51 microcontroller was programmed and simulated in Bascom environment. Two ports with 8 bit digital inputs of microcontroller were combined each other with inner

conversion calculations for supplying 16 bit digital input. Then remaining two ports were used to demonstrate function approximation results. The approximated tangent hyperbolic sigmoid function in equation (3) obtained in MATLAB 6.1 environment was concluded with the results of microcontroller implementation.

## 2. THE METHOD

The main part of the required sigmoid activation functions are to obtain Eulers'  $e^x$ . To obtain it, the Taylor series approximation in equation (1) is used with seven terms for a bounded input range between 0 to 5 volts.

$$e^x = 1 + x + \frac{x^2}{2!} + \frac{x^3}{3!} + \frac{x^4}{4!} + \frac{x^5}{5!} + \frac{x^6}{6!} \quad (1)$$

$$e^{2x} = 1 + 2x + \frac{4x^2}{2!} + \frac{8x^3}{3!} + \frac{16x^4}{4!} + \frac{32x^5}{5!} + \frac{64x^6}{6!} \quad (2)$$

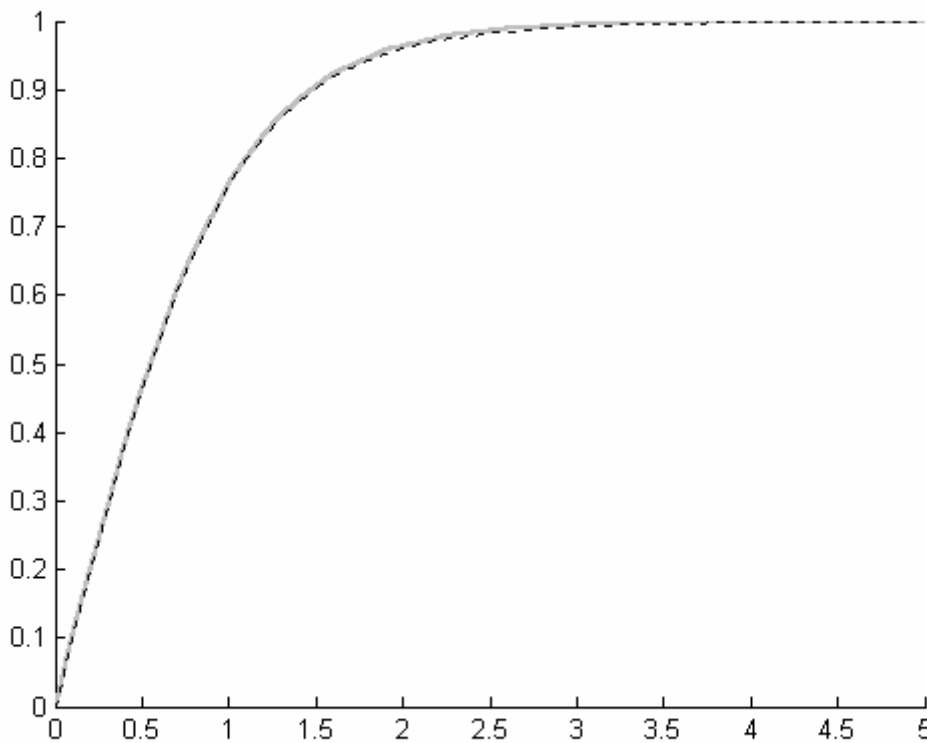


Fig 1 Graph of tangent hyperbolic sigmoid function and its seven term Taylor series approximation

Then tangent hyperbolic function is obtained as in equation (3) with the usage of equation (2).

$$\tanh(x) = \frac{e^{2x} - 1}{e^{2x} + 1} \quad (3)$$

Fig 1 compares the effectiveness of the approximation versus tangent hyperbolic sigmoid between 0 to 5 ranges. The dotted black line in Fig 1 refers to ideal tangent hyperbolic sigmoid and gray line refers to the approximation of equation (3). The maximum error between them is 0.0044. The first seven term approximation is close enough to required tangent hyperbolic sigmoid function.

The Atmel 89C51 is one of the most popular, cheap microcontroller with MCS-51 technology standard. Mathematical operation ability is limited with the basic calculation operations. It does not have floating point unit and and complicated mathematical operators neither. The approximation in equation (2) and (3) can be applicable with only usage of multiplication and addition operations, this means the microcontroller is valid for the neural network design with sigmoid function.

Total 32 bit input and output allows to 16 bit input and 16 bit output resolution with 65535 levels for each. 0.000076295 is an effective and enough digital conversion accuracy for the application.

The sigmoid activation functions have more implementation area then the existing hard limiting and pure linear activation functions. The generation of tangent hyperbolic sigmoid function on a general purpose microcontroller makes it possible to design multi layer perceptron neural networks on these cheap elements effectively

### 3. THE IMPLEMENTATION CIRCUIT TOPOLOGY

Block diagram of the test circuit is shown in Fig. 2. Two port of the microcontroller are used for 16 bit inputs. The results of the operation are sent to a the personel computer as shown in Fig. 2 using the serial port with an ICL 232 interface circuit.

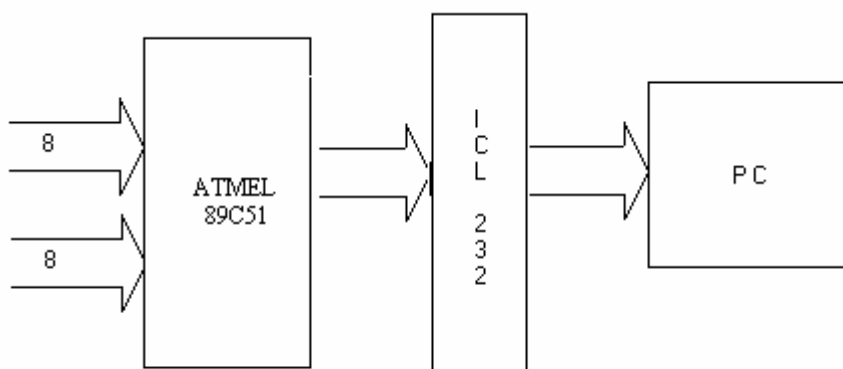


Fig. 2 Block diagram of the implementation circuit.

The flow of the operation can be summarized as;

- a) Port 1 and Port 2 of the microcontroller are read.
- b) They combined as 16 bit and converted to the analog equivalent numerical values.
- c) Tangent Hyperbolic Sigmoid function is applied.
- d) Output is sent to PC.

#### 4. THE SIMULATION AND IMPLEMENTATION RESULTS

In Fig. 3 the results of the application circuit and MATLAB 6.1 environment simulations are shown in the same figure with different line styles. They have very close lines in the operation range.

The dotted line shows MATLAB 6.1 simulation result and the solid line represents the microcontroller realization results.

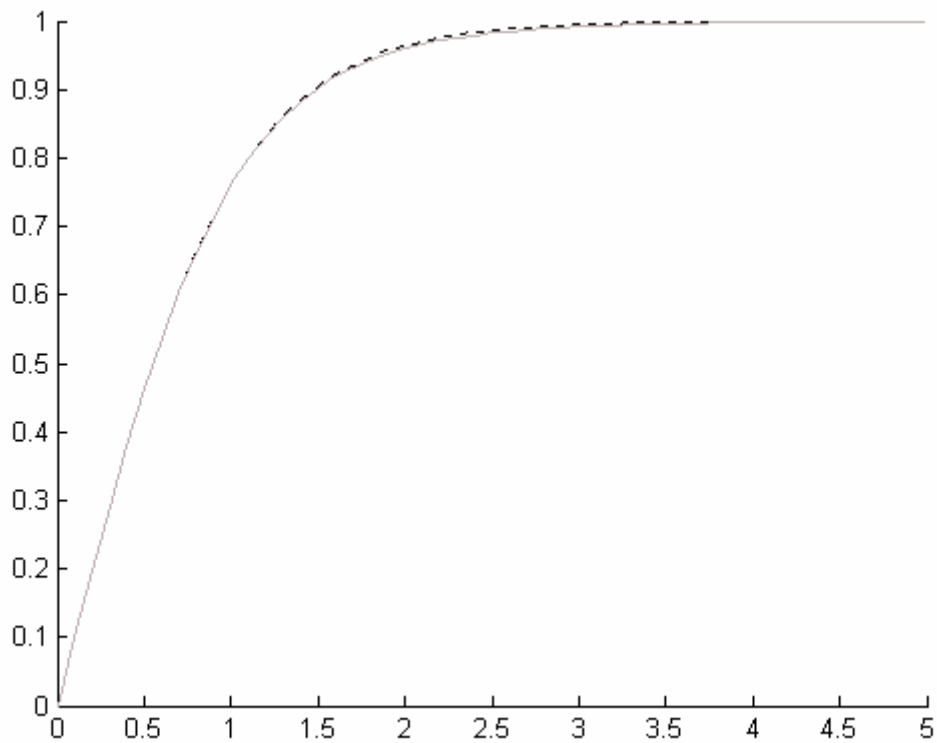


Fig 3 Simulation and Implementation of tangent hyperbolic sigmoid function

## 5. CONCLUSION

From the implementation and theoretical calculation results, it is seen that the standard microcontroller can realize a tangent hyperbolic sigmoid function with Taylor series expansion. For Multi Layer Perceptron neural network realization on standard, cheap microcontrollers this activation function realization is a milestone. The implementation has some limitations, one of the most important one is the speed inefficiency for complex feedforward networks. The cost of integrated circuit realizations may cause that the standard microcontrollers can be chosen for many applications. The given tangent hyperbolic sigmoid realization can effectively be used for any feedforward network realizations.

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