A Review On Implementation of Neuro-fuzzy PID Controller Using FPGA

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Abstract-Neuro Fuzzy (NF) computing is a popular framework for solving complex problems. The combination of neural networks with fuzzy knowledge base helps to reduce the searching space and time for achieving optimal solution. While Proportional-Integral-Derivative controllers are universal control structure and have widely used in Automation systems, Conventional PID controllers are not well for time-delayed linear and nonlinear systems. Thus Neuro-Fuzzy PID Controller is designed to enhance its performance evaluation parameter**.** This paper describes the design of Neuro-Fuzzy PID Controller using Field Programmable Gate Array. The implementation of Neuro-Fuzzy PID controller using FPGA will help for compactness to improve its speed and accuracy.

Keywords- Neuro-Fuzzy System, PID controller, FPGA, ANN, Fuzzy system, ANFIS, VHDL.

INTRODUCTION

The Fuzzy Logic is closer as to human thinking and in language than conventional logical systems [1]. Fuzzy hardware systems have been developed, including fuzzy rules bonds, fuzzy interface devices, and optical fuzzy inference devices [1]. Fuzzy logic is one of the successful applications in the control engineering field which can be used to control various parameters of the real time systems. The main problem to overcome in applications is the difficulty or uncertainty in fuzzy modeling of the linguistic structure for process [1]. While Artificial Neural Networks are mathematical models inspired from our understanding of biological nervous system [2]. They are attractive as computation devices that can accept a large number of inputs and learn solely from training samples [2]. As mathematical models for biological nervous system, artificial neural networks are useful in establishing relationships between input and out of any kind of the system [2]. That is neural network is collection of artificial neuron. Neural network can learn from data. However, the knowledge learned by neural networks has been difficult to understand .While; it is easy to understand the fuzzy rule based models because it uses linguistic terms and the structure of IF-THEN rules. However, fuzzy logic by itself cannot learn. Since neural networks can learn, it is natural to hybrid fuzzy system and neural network.

Hybrid neuro-fuzzy system (NFS) combines artificial neural network and fuzzy logic in a synergetic way [3]. Fuzzy system provide a framework to represent imprecise information and to reason with this kind of information, while neural networks enhance fuzzy systems[3] with the capability of learning from input-output samples; learning is used to adapt parameters of the fuzzy system as a membership function or rule[3]. Integrating these two methodologies, in control can lead to better technologies that take advantage of the strengths of each methodology and at the same time overcome some limitations of individual techniques [2].

Conventional proportional-integral-derivative (PID) controllers are well known and have been extensively used for industrial automation and process control. PID controllers are simple, easy to understand and implement in hardware and software, and do not require a process model for initialization [5] or operation [5]. Many nonlinear processes can satisfactory controlled using PID controllers provided that controller parameters are tuned well. The implementation of PID controllers using microprocessors and DSP chips is old and well known, whereas very little works can be found in the literature on how to implement PID controllers using FPGAs.

The Field Programmable Gate Array (FPGA) is one of the most powerful chips among the programmable electronic devices. The preparation and execution of the code with such elements is unique. In the case of FPGA hardware reconfiguration is realized, and during the implementation of an algorithm, the connection of logic elements is changed in the structure of a chip. Thus programming of the FPGA means hardware configuration of the chip. In result parallel calculations are possible. Low costs and high performance lead to many applications of FPGAs in industrial systems.

LITERATURE REVIEW

The literature survey carried out related to impact in the study of Fuzzy system, neural network, Neuro-Fuzzy system and PID controller.

Amit Kr. Singh, Manjari Mehrotra and AK Pandey[1],This paper describes the Self Tuning Fuzzy PID controller developed to improve the performance of the plants having 2nd order, 3rd order and 5th order system. Here, the methodology of the fuzzy logic controller appears very useful when the processes are too complex for analysis by conventional quantitative techniques or when the available sources of information are interpreted qualitatively, inexactly. The performance of the plants has improved significantly as compared to conventional PID controller.

Ines del Campo, Javier Echanobe, Guillermo Bosque, and Jose Manuel Tarela [3], here the design of two different on-chip approaches are presented: a high-performance parallel architecture for offline training and a pipelined architecture suitable for online parameter adaptation. This approach is suitable for developing efficient implementations for already known application areas of embedded NFS.

Abdesselem Trimeche, Anis Sakly, Abdelatif Mtibaa, and Mohamed Benrejeb [4], in this paper a digital PID controller implemented in FPGA technology is a configurable controller in terms of latency, resolution, and parallelism. Implementing PID controllers on FPGAs features speed, accuracy, power, compactness, and cost improvement over other digital implementation techniques.

Emad Ali [5], here an online tuning method based on time-domain performance specification is proposed to determine the parameters of standard PI controllers. The method uses a process model to predict the future output and to detect the specification violation. Numerical testing of the algorithm on a CSTR and on an evaporator example shows that better performance can be achieved for both set point change and load disturbance.

J.J Blake ,L.P. Magurie,T.M Mc Ginnity,B. Roche,and L.J. McDaid[6], This paper discuss the implementation of fuzzy system, neural network and fuzzy neural network[FNN] comparatively using FPGA.The drawback of this approach is cost effective for high volume applications.

.Daijin Kim [7], implemented fuzzy logic controller on the reconfigurable FPGA system where the FPGA chip is consequently reconfigured with one module at a time by using the run time configuration method. The FPGA implementation for proposed FLC can be applicable to the real time control because it can compute fuzzy operation very quickly.

Chuen Chain Lee [8], here general methodology for constructing an FLC and assessing its performance is described here fuzzy control is based on a fuzzy logical system which is much closer in the spirit of human thinking and natural language than traditional logic system. The consistency of rules may be improved through the use of fuzzy clustering of fuzzy control rules.

Ronald R. Yager, and Dimitar P. Filev[9], here correspondence addresses the problems of structure and parameter identification of fuzzy models, This allows us to simplify the problem of structure identification by replacing identification of membership functions of input variables with identification of the centers of cluster-like regions. The unified approach to fuzzy modelling developed in correspondence combines the problems of structure and parameter identification of fuzzy models.

Vikram Chopra, Sunil K. Singla, Lillie Dewan[10] , This paper presents the intelligent methods based on fuzzy logic, artificial neural network (ANN), adaptive neuro fuzzy inference system (ANFIS) and genetic algorithms (GA) for tuning a PID controller. Simulation results show that the best performance has been achieved by ANFIS in terms of settling time and overshoot while the moderate performance has been given by ANN tuned PID controller as it reduces the overshoot and undershoot to a great amount in comparison to the Zeigler Nichols method.

Supah sahin, Yasar Becerikli, and Suleyman Yazici [11], implemented neural network in hardware using FPGA, Digital system architecture is presented using Very High Speed Integrated Circuits Hardware Description Language (VHDL) and is implemented in FPGA chip. The resultant neural network are modular,compact,and efficient and the number of neuron, no. of hidden layers and no. of inputs can be easily changed.

A.Muthu ramalingam, S Himavathi, and E Srinivasan [12], here neural network is implemented with its issues and applications. Using the proposed method of implementation a neural network based application,a Space vector modulator for a vector-controlled drive is presentedThe NN based SVM is designed to be independent for inverting switching frequency & bit precision is investigated.

Al-Kazzaz, S.A, and Khalil, R.A [13], This paper proposes three different architectures for implementing an artificial neuron model, with three types of processing techniques: serial, partial parallel, and full parallel. A H/W implementation results in a higher performance with lower flexibility, while the hardware/software Co-design Implementation shows a moderate performance, flexibility, and usage area.

Prof. Vikas Gupta,Dr Kavita Khare , Dr R. P. Singh[14],This paper explains a method for the design and implementation of multiplierless digital PID controller based on Field Programmable Gate Array (FPGA) device. Implementing the multiplierless PID controller on FPGA gives better rise time as well as settling time as seen in the results. Also implementing PID controller on FPGA features speed, accuracy, power, compactness, and cost improvement.

Azar,and Ahmad Taher[15], here different methods are presented that used for structure and parameter identification in neuro-fuzzy systems, fuzzy system that is constructed by expert knowledge alone will usually not perform as required when it is applied because the expert can be wrong about the location of the fuzzy sets and the number of rules. By supporting these various levels of transparency, the proposed neuro-fuzzy modelling methodology significantly aids the process of knowledge discovery and model validation.

Jyh-Shing Roger Jang, and Chuen-Tsai Sun [16], This paper introduces the design method for ANFIS for both fuzzy system and neural network in modeling and control application with addressing the future approaches for neuro-fuzzy system. The modeling problem includes structure determination problem.

Hideyuki Takagi[17], This works proposes the ease of fusing NN+FS technologies based on the similarities of the data flow network structures and the non-linearity realization strategies of NNs and FSs.This technology has become a mainstay feature in product development.

S.R. Khuntia, K.B. Mohanty, S. Panda and C. Ardil [18], here two Fuzzy logic based controllers namely; Fuzzy control and Neuro-fuzzy control are proposed and the performance these controllers are compared with both P-I and I-P controllers.A Neuro-Fuzzy controllers can replace P-I, I-P and Fuzzy controllers for the speed control of dc motor drives.

Rajesh Nema, Rajeev Thakur,and Ruchi Gupta[19] , In this paper, work is focused in designing on building a multi-channel PID controller by Field Programmable Gate Arrays (FPGAs). To overcome the hardware complexity by the use of more processors for multi channel, we are using single PID controller for multi channel.It Minimize the cost of overall system by eliminating the PWM Modulator and A/D Convertor which give advantages over Power Consumption and Delay.

Rahib Hidayat Abiye [20], This paper presents the development of recurrent neural network based fuzzy inference system for identification and control of dynamic nonlinear plant. The learning capability of RNFIS allows automatically construct itself and to deal with non-stationary plants. The simulation result of identification and control systems based on RNFIS are compared with other types of neural network based system. The performance of RNFIS system is better than NFIS and RNN system. Result of comparative estimation demonstrates the efficiency of presented approach.

James G. Eldredge, and Brad L. Hutchings [21], Here it implements the popular back propagation training algorithm as three distinct time-exclusive FPGA configurations: feed-forward, back propagation and update which has been successfully implemented on FPGA. The run-time reconfiguration can be used to implement practical systems that use FPGA resources more effectively and with more exibility .

A.Manzoul, and D.Jayabharathi [22], This paper explores the use of FPGA technologies to implement FLCs with two methodologies logic synthesis of the boolean equations describing the controller I/O, O/P relations. The second is hardware to implement the fuzzy algorithm with CAD tools. The implementation will be free of design errors.

Nazeih M. Botros, and M.Abdul-Aziz [23], This paper describes hardware implementation of a fully digital and fully interconnected feed forward back propagation artificial network using Xilinx FPGAs. Reconfigurability and adaptability are the main features of this hardware.

Fares Sassi , Mehdi Abbes, Abdelkader Mami [24], This paper proposes an implementation of a synthesizable Very High Speed Integrated Circuits Description Language program of Proportional-Integral-Derivative controller on a map XC3S700A Xilinx Starter Kit using the Xilinx ISE 10.1 software. In the current investigation, an implementation of PID controller on a map XC3S700A, FPGA-based, is performed by writing a synthesizable VHDL integer program. The use of integer type provides good results because it solves the over flow problems during the computations.

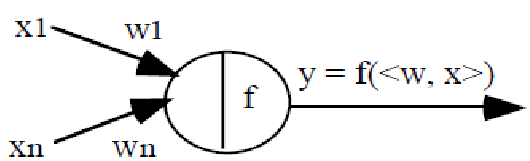
Ansgar P. Ungering, Dieter Herbst, Anselm Weyergraf,and Karl Goser[25], This paper presents an architecture of a mix mode fuzzy controller architecture with new idea to use the pointers instead of analog values and the prototype has been implemented using FPGA. The advantages are that there is no need for A/D and D/A converters and that the controller is fully programmable.

From the survey of the available literature,it would be concluded that FPGA have become an alternative solution for the realization of digital control systems, previously dominated by the general purpose microprocessor systems and DSP chips.

METHODOLOGY

Neuro-Fuzzy System:-

Consider a simple neural net in shown in Figure below:-



All signals and weights are real numbers. The input neurons do not change [26] the input signals so their output is the same as their input. The signal xi interacts with the weight [26] wi to produce the product pi = wixi, i = 1, . . . , n. The input information pi is aggregated, by addition, to produce the input [26]

net = p1 + · · · + pn = w1x1 + · · · + wnxn,

to the neuron. The neuron uses its transfer function *f*, which could be a sigmoidal function,

$$f(t) = \frac{1}{1+e^{-t}}$$

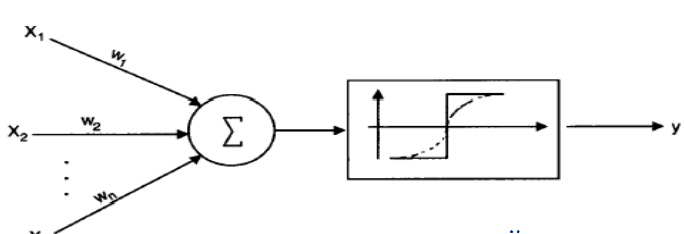
to compute the output

y = f(net) = f(w1x1 + · · · + wnxn).

This simple neural net, which employs multiplication, addition, and sigmoidal *f*, will be called as regular (or standard) neural net.[26]

A hybrid neural net is a neural net with crisp signals and weights and crisp transfer function. However, (i) we can combine xi and wi [26] using some other continuous operation; (ii) we can aggregate the pi's with some other other continuous function; (iii) f can be any continuous function from input to output.[26] We emphasize here that all inputs and outputs and the weights of a hybrid neural net are real numbers taken from the unit interval[26]. A processing element of a hybrid neural net is called fuzzy neuron.

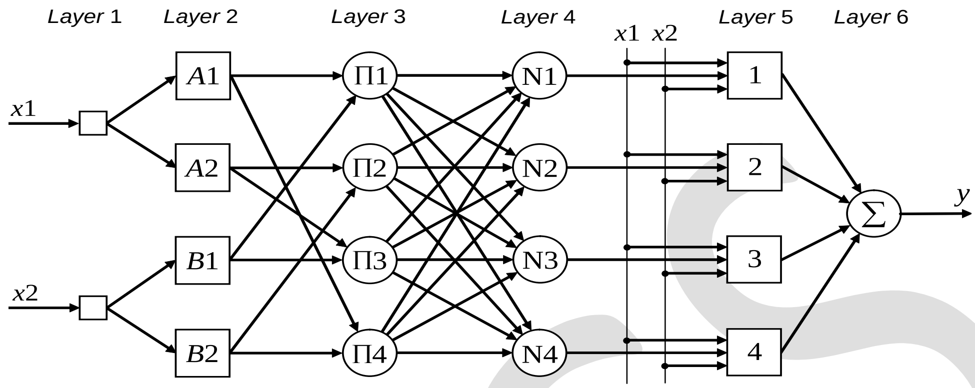
Fuzzy model of artificial neuron [27] can be constructed by using fuzzy operations at single neuron level [27]



y= g(w.x)

x = (x1, x2,… xn); w= (w1, w2,… wn [27]

ANFIS: Adaptive Neuro-Fuzzy Inference System [26]



Layer 1 is the input layer. Neurons in this layer simply pass external crisp signals to Layer 2.

Layer 2 is the fuzzification layer [28] neurons in this layer perform fuzzification while for Jang's model fuzzification neurons have a bell activation function [28].

Layer 3 is the rule layer. Each neuron in this layer corresponds to a single Sugeno-type fuzzy rule [28]. A rule neuron receives inputs from the respective fuzzification neurons and calculates the firing strength of the rule it represents [28]. In an ANFIS, the conjunction of the rule antecedents is evaluated by the operator product [28]. Thus the output of neuron i in Layer 3 is obtained as [28],

$$y_i^{(3)} = \prod_{j=1}^{k} x_{ji}^{(3)} \qquad y_{\Pi 1}^{(3)} = \mu_{A1} \times \mu_{B1} = \mu_1,$$

where the value of μ_1 represents the firing strength or the truth value of Rule 1[28].

Layer 4 is the normalisation layer each neuron [28] in this layer receives inputs from all neurons in the rule layer and calculates the normalised firing strength of a given rule [28].

The normalised firing strength is the ratio of the firing strength of a given rule to the sum of firing strengths of all rules [28]. It represents the contribution of a given rule to the final result. Thus, the output of neuron i in Layer 4 is determined as [28],

$$y_i^{(4)} = \frac{x_{ii}^{(4)}}{\sum_{j=1}^{n} x_{ji}^{(4)}} = \frac{\mu_i}{\sum_{j=1}^{n} \mu_j} = \bar{\mu}_i \qquad y_{N1}^{(4)} = \frac{\mu_1}{\mu_1 + \mu_2 + \mu_3 + \mu_4} = \bar{\mu}_1$$

Layer 5 is the defuzzification layer here each neuron in this layer is connected to the respective normalisation neuron and also receives initial inputs x_1 and x_2 where defuzzification neuron calculates the weighted consequent value of a given rule as[28],

$$y_i^{(5)} = x_i^{(5)} \left[k_{i0} + k_{i1}\, x1 + k_{i2}\, x2\right] = \bar{\mu}_i \left[k_{i0} + k_{i1}\, x1 + k_{i2}\, x2\right]$$

Where $x_i^{(5)}$ is the input and $y_i^{(5)}$ is the output of defuzzification neuron *i* in Layer 5, and k_{i0}, k_{i1} and k_{i2} is a set of consequent parameters of rule i [28].

Layer 6 is represented by a single summation neuron this neuron calculates the sum of outputs of all defuzzification neurons and produces the overall ANFIS output y [28],

$$y = \sum_{i=1}^{n} x_i^{(6)} = \sum_{i=1}^{n} \overline{\mu}_i \left[k_{i0} + k_{i1}\, x1 + k_{i2}\, x2 \right]$$

A proportional integral derivative (PID) controller is the most commonly used controller in controlling industrial loops due to its simple structure, robust nature and easy implementation. Tuning a PID controller is an important task. Hence PID controller is used with neuro-fuzzy rules to enhance its evaluation parameters.

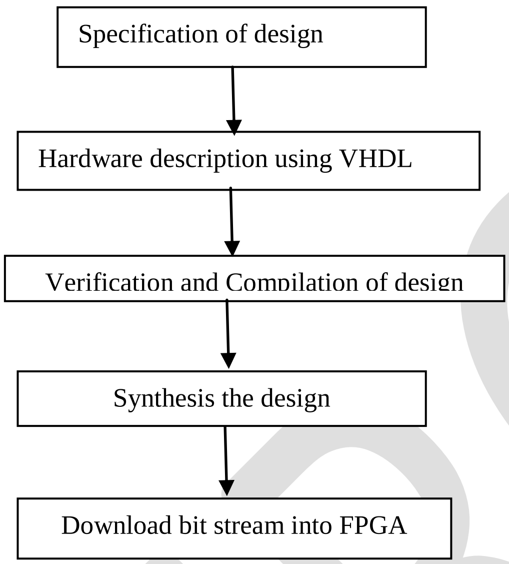


Fig:-Design flow of Project.

In the flow graph above Specification of design shows the specification of PID controller and neuro-fuzzy system design .And Hardware description using VHDL presents the VHDL code of the PID controller and neuro-fuzzy system. After that in Verification and Compilation of design the VHDL code of the PID controller and neuro-fuzzy system will be compiled in Model Sim software. The next step id Synthesis the design where the code will be synthesis in Xilinx FPGA. While in next step which is Download bit stream into FPGA will done in Xilinx ISE ISE design suite.

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CONCLUSION

This paper presents a survey on various implementation techniques of fuzzy systems, neural network, neuro-fuzzy system, PID controller and FPGA. This overview of various information about Neuro-Fuzzy system, PID Controller and FPGA Prototype focuses on its usability and challenges. It also gives conceptual overview of methodology. The Future development of Neuro-Fuzzy PID controller using a particular application using FPGA will improve its flexibility and re-usability.

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