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Digital Design Systems Controlling Using FPGA Realization

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Abstract

The plan and acknowledgment of the Adaptive Neuro-Fuzzy Inference System (ANFIS) regulator dependent on Field Programmable Gate Array (FPGA) is introduced in this paper. The regulator is expected to control the temperature of the clinical broiler. An epic plan of computerized ANFIS is presented here for the user interaction. Various regulators are planned and their outcomes are contrasted utilizing MATLAB program to show the ANFIS prevalence. The planned regulators tried for cell society's application at 37.5℃. A decrease is made for the planned computerized ANFIS because of the utilized FPGA limits. The decreased plan limits the used cuts from 366% to 3% and LUTs from 364% to 3%. The diminished plan arrived at an ideal size for this regulator to use a less memory size. An ongoing FPGA execution of the proposed advanced ANFIS have been done and checked through Xilinx ISE 14.6 utilizing the VHDL language. An examination between the reenactment and execution results is made. The coordination between these outcomes demonstrates the viability and vigor of the proposed computerized ANFIS and the magnificent exhibition of the FPGA based regulator.

Keywords: Medical Oven Modeling; Proportional Integral & Derivative Controller; Neural Network; ANFIS; Digital ANFIS; FPGA.

1. Introduction

The control of temperature of delicate for some applications, for example, clinical and natural is a significant issue particularly when the temperature is a basic condition. The assessment of exact and capable computerization that fit for filling such applications is the need for the decision of an amazing and fitting controller to meet these requirements.

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The clinical stoves take an exceptional indisputable quality for their sensitive fundamentals of a careful control. The standard methodologies don't give the essential control precision; such ovens need significantly changed controllers to ensure a great and prosperity creation [1].

FPGA is unadulterated equipment, so it's reasonable to control the temperature. The solid, field programmable, adaptable in plan and little size attributes of FPGA increment its reasonableness [2]. Diverse control strategies were applied on temperature systems, like Proportional Integral Derivative (PID), Neural Network (NN), Fuzzy Logic Controller (FLC) and others [3]. The blend of the two advances; Artificial Neural Networks (ANN) and Fuzzy Inference System (FIS) can give better innovation that can take the benefits of every approach's solidarity, and all the while defeat a portion of the individual strategies constraints. The cross breed Neuro Fuzzy regulator is an incredible strategy that used to restrict the impediments of the Fuzzy Logic System (FLS) and ANN. The test is the usage of these smart regulators on coordinated circuits. The most serious one is the FPGA which is the awesome limit and execution. The FPGA is helpful for quick execution and confirmation [4].

Various investigates are made in the field of actualizing NN and FL on FPGA with various frameworks. Z. Runjing et al (2011), proposed Fuzzy regulator dependent on FPGA that controlling the temperature to meet the clinical necessities [2]. Bouhedda M. (2013), introduced ANFIS linearizer dependent on FPGA to linearize the nonlinear sensor's trademark [5]. T. Tamas et al (2015), introduced a usage and configuration stream of NFC Intellectual Property center (IP) for FPGA by utilizing Xilinx Vivado the High-Level-Synthesis apparatus (HLS) and C-language, the plan actualized utilizing the number activity just [6]. C eddine LACHOURI et al (2016), presented an (FPGA) execution of "(ANFIS)" for controlling temperature and mugginess inside a tomato nursery. The amusement results have shown the efficiency of the realized controller [7]. H. Layla et al (2018), the explanation behind using the single neuron PID controller is to create an ideal combination rate as a control signal without help from anyone else change for PID controller limits and subsequently execute it on FPGA. The Simulation results show the viability of the suggested control plots in after the ideal BIS for all of patients' cases [8]. M. Reem et al (2018), proposed a portable robot with an "Counterfeit Neural Network (ANN)" controller executed on Altera FPGA little board with far off capacity to move to a specific distance by avoiding the impediment. This system uses a Nios II/e sensitive focus processor fired up in ANN control of the engines subject to the data given by the sensors. The arrangement shows versatility in gear and programming, where the arrangement can be changed adequately by installing more stunning limits in light of the restriction of FPGA instead of a current microcontroller or central processor based arrangement. [9]. A. H. Issa et al (2021), proposed a reconfigurable insightful regulator for portable robot. The control framework engineering was adjusted by programming called reconfigurable control framework, and the regulator was planned and executed using "Field Programmable Gate Array (FPGA)" innovation [10]

For diminishing intricacy and cost, a proposed computerized ANFIS regulator planned in this examination. A continuous FPGA execution has been cultivated and checked through Xilinx ISE

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14.6 of the proposed computerized plan for the clinical stove. The VHDL code for the regulator is produced, ordered and downloaded on Spartan 3A/A FPGA unit.

2. Modeling

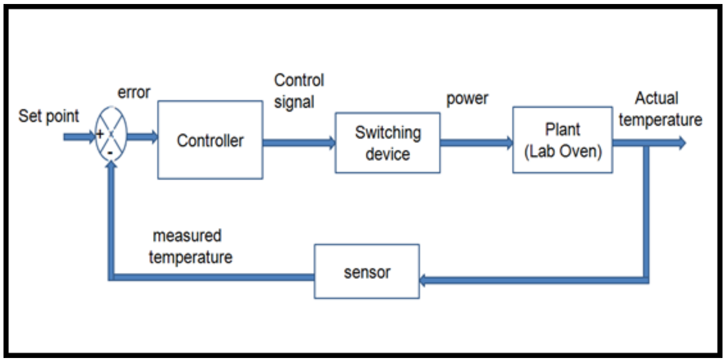

Figure 1 the controlled heating system block diagram.

The numerical model for the Laboratory Oven has been gathered depending upon heat move conditions [11], [12], and the Laboratory Oven design features it is a mix of radiation and convection, as given in the conditions (1) to (10) individually [13].

$Q_{acc}(t)=Q_{in}(t)-Q_{loss}(t)$ (1)

Where, Qacc(t) presents the accumulated heat, Qin(t) is the input heat and Qloss(t) is the lost heat.

$MC_p dT_o/dt=Q_{in}(t)-(Q_{conv}+Q_{rad})$ (2)

M represents the Mass flow; CP is Specific heat under constant pressure, TO is the Oven temperature, Qconv is convection heat and Qrad is radiation heat.

$dT_o/dt= 1/(MC_p)\ Q_{in}(t)- [((h_{conv}+h_{rad})\ A_{wall})/(MC_p)\ (T_{wall}-T_{air})]$ (3)

Where, hconv and hrad are the convection and radiation coefficients of heat transfer respectively.

$R= 1/(h\ A)$ (4)

To simplify the analysis

$C=MC_p$ (5)

And by compensation equation (5) in equation (3) yields

$dT_o/dt = 1/RC\ [RQ_{in}(t)- (T_{wall}-T_{air})]$ (6)

In steady state:

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$RC\ dT_o/dt = RQ_{in}(t)-T_o$ (7)

Let, τ is time constant = R C, TO = X and R=K, substitute in (7):

$\tau\ dx/dt + X = KQ_{in}(t)$ (8)

By using Laplace transform for equation (8) we get

$\tau SX(S)+X(S)=KQ_{in}(S)$ (9)

Finally, the transfer function is:

$G(S)=K/((\tau s+1))\ e^{(-\tau_d s)}$ (10)

3. Architecture of ANFIS

The learning stage based the variation dependent; it is a brand name ANFIS include [14]. The design of ANFIS is appeared in Figure 2. The essential solicitation Takage-Sugeno ANFIS controller arranged here to have two information sources (blunder (e) and change in mistake (de)) and one yield. The half and half calculation is the used learning technique for data getting ready. Usually, the ANFIS segment has two information sources and one yield subject to the ordinary IF-THEN Takage-Sugeno rule [15], [16]:

Related to Figure 2;

If e is Ai and de is Bi,then;
$P_j= k_{0j}+k_{1j}+k_{(2j)}$ (11)

Where, Pj is the output, j is the principles number and k is resulting boundary.

The ANFIS structure has 5 elements of major layers' as given:

Layer-1: This layer makes the MFs (Fuzzification layer).

Layer-2: The ending strength is delivered present here as the standards input space (Rules layer).

Layer-3 This layer standardizes the layer-2 yields (Normalization layer).

Layer-4 determines the rules weighted coming about boundaries (Defuzzification layer).

Layer-5 discovers the overall results of the ANFIS (Summation layer).

The calculation of ANFIS learning is a blend which is a blending of two areas:

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1-Move forward to determine the yield (boundaries of resulting) till layer-4 utilizing the calculation of Least Square strategy.

2-Move in reverse to find out boundaries of the info MFs (boundaries of reason) using the calculation of steepest-drop technique.

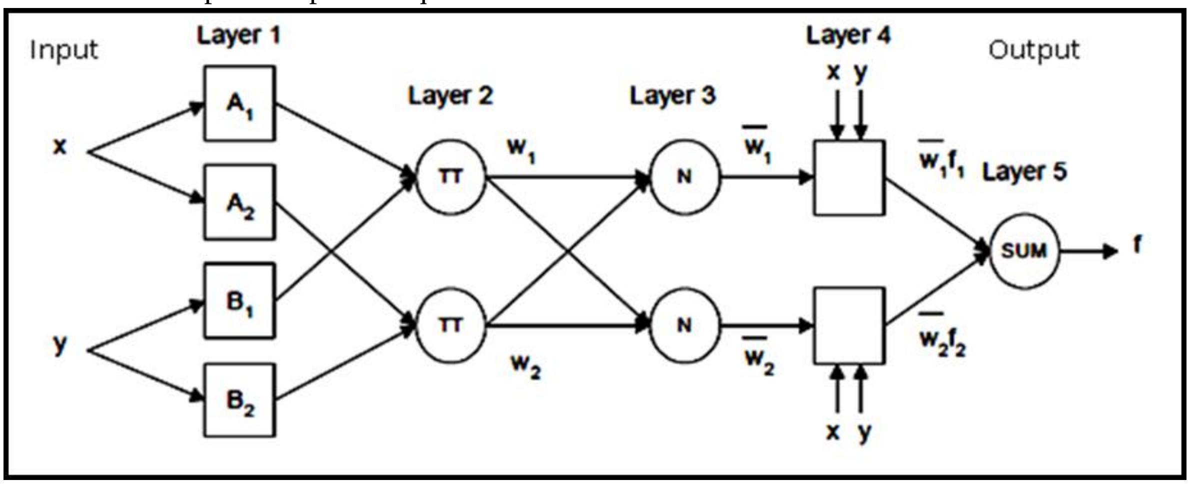

Figure 2 the ANFIS architecture.

4. Simulation Results

The medical oven is a practical laboratory oven has a transfer function with first order and time delay as:

$$G(s)=0.7/(13.3s+1)\ e^{(-26s)} \quad (12)$$

The program is simulated in MATLAB for heating system. The open loop reaction of the oven is appeared in Figure 3. The close loop framework recreated with various regulators to show the ANFIS prevalence over different regulators and over give the appropriate preparing information to the ANFIS. The time of sampling is 1 second, the signal of control reaches from 0 watt - 250 watts as indicated by the heater constraints. The heater constrained by a TRIAC power switch utilizing various regulators recorded as, PID, NN and the ANFIS to make the oven temperature keep at 37.5℃ for cell cultures application. The simulation results are shown in Figure 4; it very well may be seen from the outcomes that the designed ANFIS regulator give some ideal outcomes surpasses different regulators.

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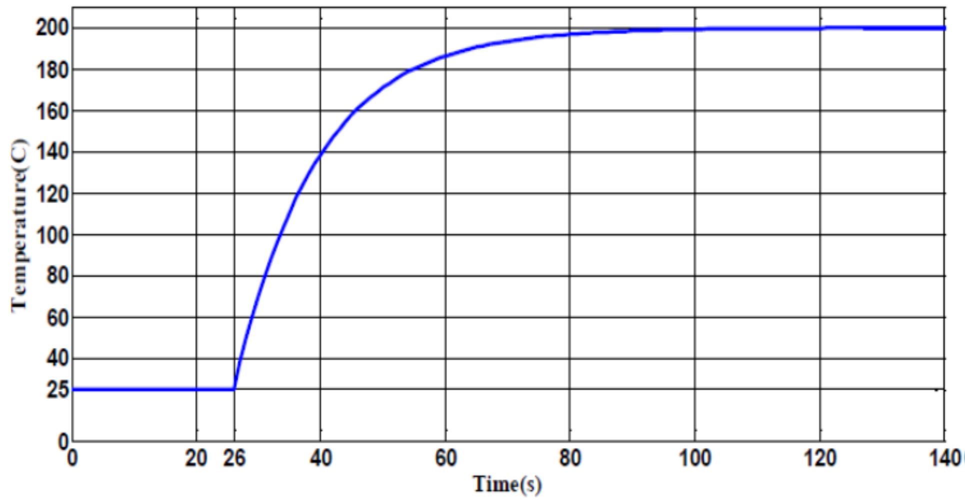

Figure 3 the T.F. response for open loop of the practical laboratory oven.

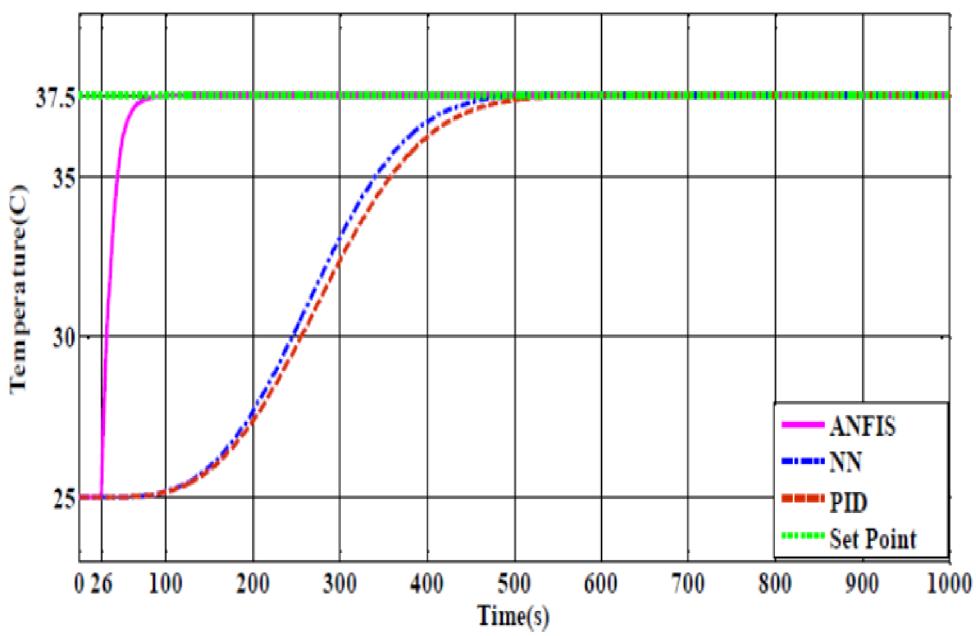

Figure 4 the response of heating system for cell cultures application

with PID, NN and ANFIS controllers

5. FPGA Implementation

In order to implement the ANFIS controller on FPGA board, a proposed digital ANFIS is designed here. The proposed design architecture and performance will be clarified in the next sections.

A. Proposed Digital ANFIS Design

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The new design is depending on the simplified output equation of the ANFIS controller as given in (13).

$$O_f = \frac{\sum_{i=1}^{9} w_i Z_i}{\sum_{i=1}^{9} w_i} \qquad (13)$$

Where, Of represents the final output of the digital ANFIS controller, Zi is the polynomial of the premise parameters as indicated in Figure 5.

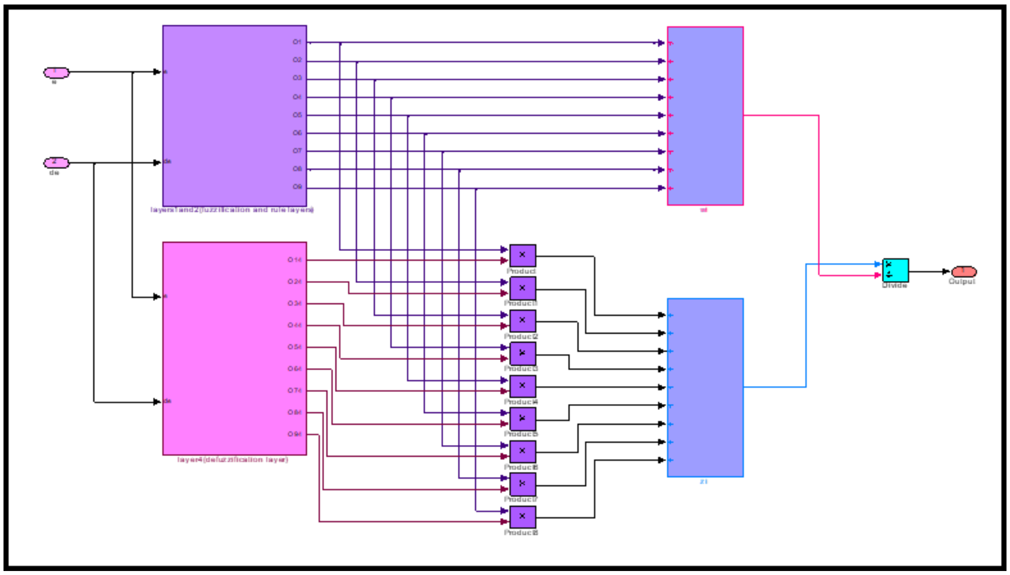

Figure 5 the second new design of the proposed digital ANFIS controller.

Therefore, the new design is reduced in size with exactly the same output response as indicated in Figure 6 in a comparison with the MATLAB-based ANFIS controller.

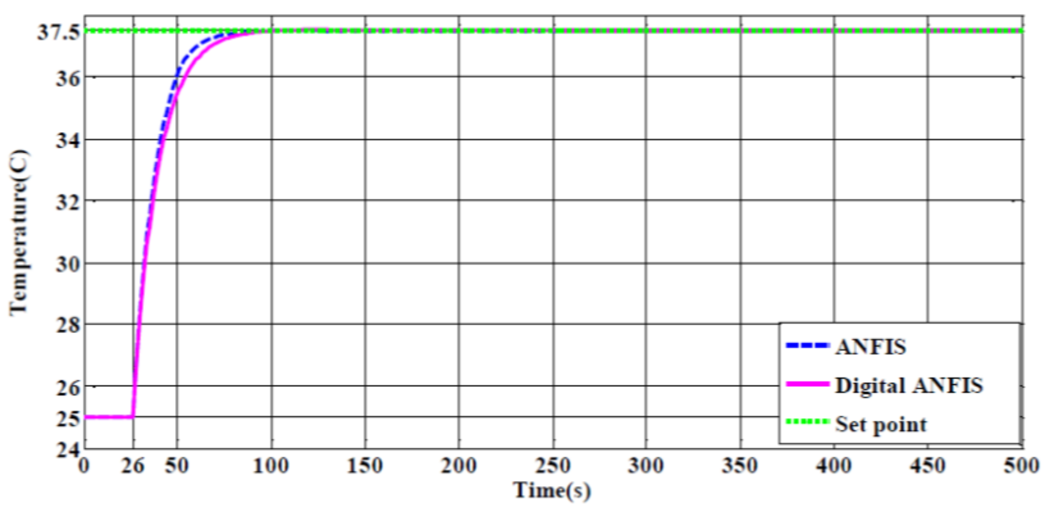

Figure 6 heating system responses comparison between ANFIS and digital ANFIS controller for cell cultures.

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A reduction process has been made on the digital ANFIS, where only the effective parts of the design are taken. This process reduces the number of Membership Functions (MFs), rules and consequently, the utilized blocks of the digital ANFIS. The reduced design represents the optimum design of the proposed digital ANFIS. The reduction process minimized the controller size to be suitable for the implementation on Spartan 3A/AN FPGA. The comparison of the reduced and unreduced digital ANFIS is shown in Figure 7.

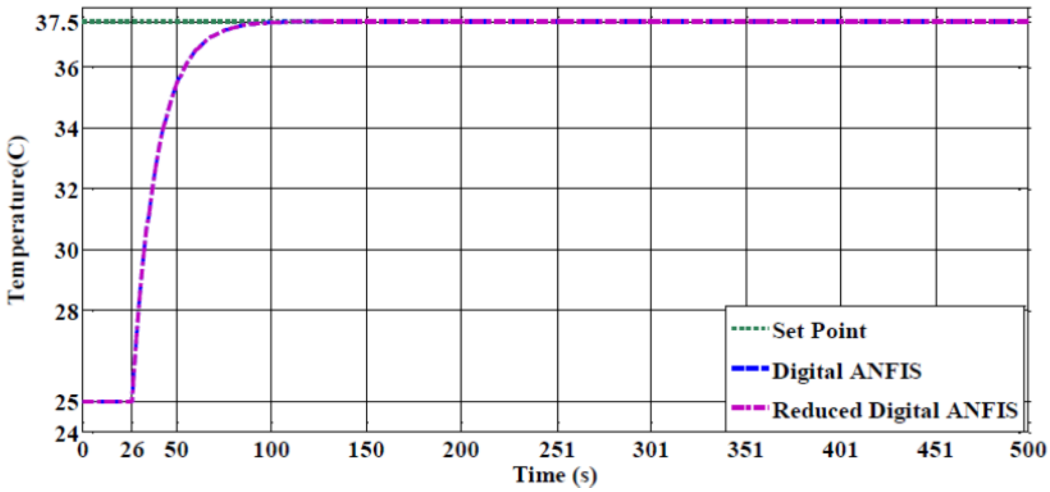

Figure 7 the comparison of the reduced & unreduced digital ANFIS.

The next step is the implementation of the digital ANFIS on FPGA. The implementation and verification process has been done through connecting the FPGA kit with the Laptop which represents the simulated heating system via USB cable as shown in Figure 8.

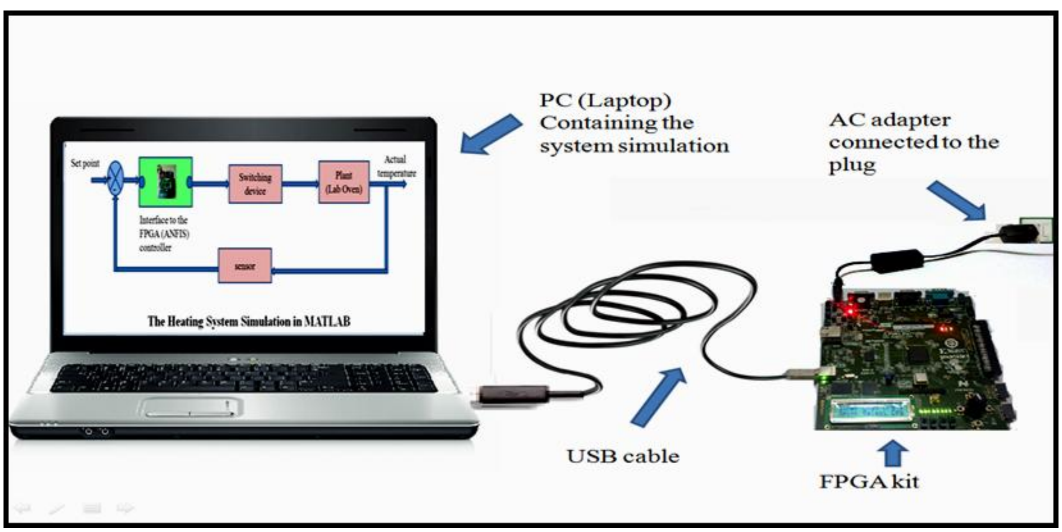

Figure 8 the implementation and verification process.

B. FPGA Realization

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The design summery reports for the implementation of the unreduced and reduced digital ANFIS are shown in tables (1) and (2) respectively.

Table (1): The summery report of the unreduced digital ANFIS controller using Xilinx ISE 14.6 based on Spartan 3A/AN FPGA.

Device Utilization Summary				
Logic Utilization	**Used**	**Available**	**Utilization**	**Note(s)**
Number of 4 input LUTs	38,827	11,776	329%	OVERMAPPED
Number of occupied Slices	21,604	5,888	366%	OVERMAPPED
Number of Slices containing only related logic	21,604	21,604	100%	
Number of Slices containing unrelated logic	0	21,604	0%	
Total Number of 4 input LUTs	42,959	11,776	364%	OVERMAPPED
Number used as logic	38,827			
Number used as a route-thru	4,132			
Number of bonded IOBs	96	372	25%	
Number of MULT18X18SIOs	20	20	100%	
Average Fanout of Non-Clock Nets	2.17			

Table (2): The summery report of the reduced digital ANFIS controller using Xilinx ISE 14.6 based on Spartan 3A/AN FPGA.

Device Utilization Summary				
Logic Utilization	**Used**	**Available**	**Utilization**	**Note(s)**
Number of 4 input LUTs	364	11,776	3%	
Number of occupied Slices	229	5,888	3%	
Number of Slices containing only related logic	229	229	100%	
Number of Slices containing unrelated logic	0	229	0%	
Total Number of 4 input LUTs	437	11,776	3%	
Number used as logic	364			
Number used as a route-thru	73			
Number of bonded IOBs	106	372	28%	
Number of MULT18X18SIOs	11	20	55%	
Average Fanout of Non-Clock Nets	1.42			

As shown in Table (1) and (2), the reduced digital ANFIS controller used 364 of the input LUTs so utilizes 3% of the available and 437 as total number of the four input LUTs where still

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utilizes3% of the total available number. The number of occupied slices is 229 so, it utilizes 3% of the available number of slices, and took an 11 of MULT18×18SIOs so utilizes 55% from the available number.

The reduced digital ANFIS controller gives an optimum design for the used application. The reduced design takes a very small area from the available of Spartan 3A/AN FPGA saving in that the chip size and cost.

After downloading the digital ANFIS, the FPGA externally connected to the PC (Laptop). The conventional controller of the heating system in MATLAB Simulink replaced by the real FPGA kit as the hardware ANFIS controller for the Lab Oven as illustrated in Figure 9 and then making the verification.

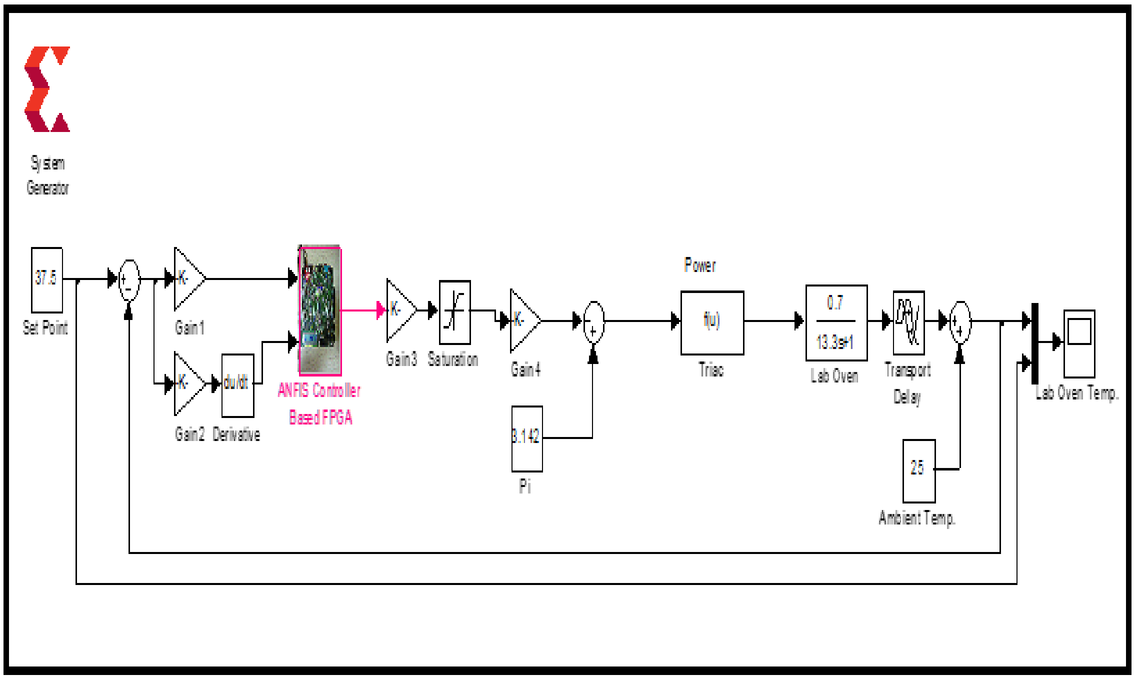

Figure 9 the controlled heating system based Real-Time FPGA controller.

The verification of the implemented ANFIS controller based on the FPGA is shown in Figure 10.

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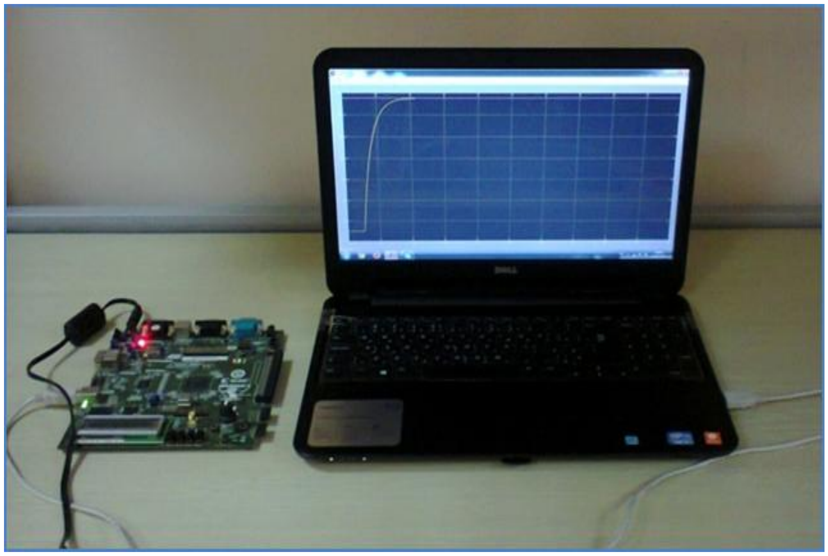

Figure 10 implementation and verification setup.

After running the heating system simulation with the FPGA as the ANFIS controller, the results for the cell cultures application were obtained. These results compared with the simulation results of the reduced digital ANFIS controller before the implementation as indicated in Figure 11.

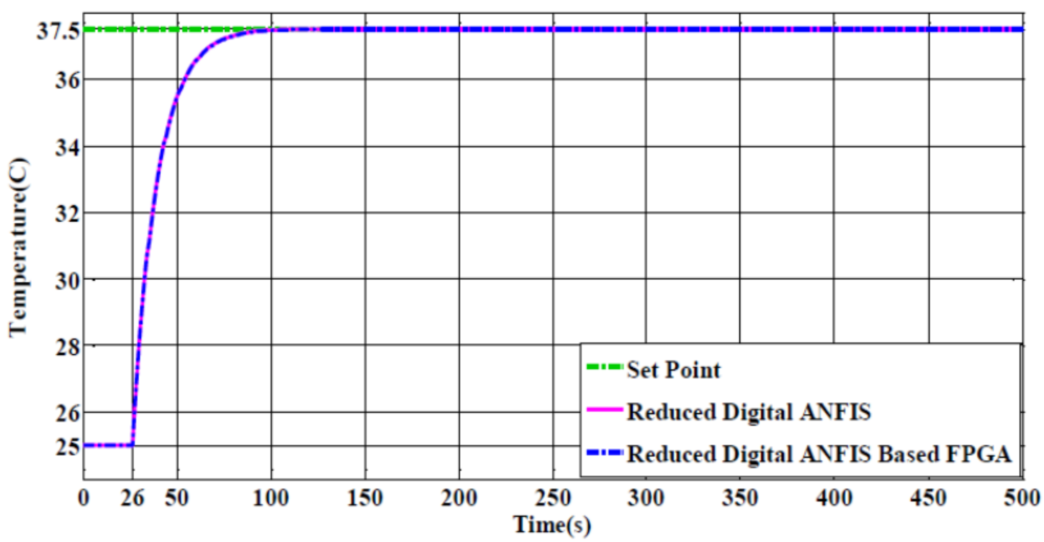

Figure 11 the heating system response comparison for the reduced digital ANFIS controller before and after hardware implementation based on the FPGA.

6. Conclusion

The acquired outcomes show that the ANFIS regulator is more appropriate for delicate clinical applications. The proposed advanced ANFIS regulator gives results that extremely near that of MATLAB-based ANFIS regulator. The fundamental Digital ANFIS configuration can be

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utilized for some other application just with differing the constants. It can undoubtedly use without the requirement for reviewing the FIS of the planned ANFIS regulator each time it opens and run with the framework recreation. The computerized ANFIS regulator has the likelihood to be diminished to an ideal size. The diminished computerized ANFIS regulator gives the very same reaction as the regulator before decrease with more modest size. The ANFIS regulator of decreased size can be actualized on a more modest chip holds in that the size and therefore the expense. An ongoing FPGA execution has been cultivated and confirmed utilizing portrayal of framework in PC and that gives a diminishing true to form and cost with precise execution.

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