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MEDICAL OVEN TEMPERATURE CONTROL BASED ON SOFT COMPUTING TECHNIQUES

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ABSTRACT: - Different types of controllers are designed in this research to control the temperature of medical oven. These controllers represented by the conventional PID, the intelligent Neural Network (NN), Fuzzy-Logic controller (FLC) and the hybrid Adaptive-Neuro-Fuzzy-Inference-System (ANFIS) controller. The controllers designed using MATLAB R2012a version 7.14 both m-file and Simulink. Two laboratory ovens (lab ovens) with different mathematical models are used. A comparison between the designed controllers has been made, first with step response with the first oven and second with different set points of four medical applications for the second practical lab oven, the ANFIS superiority over the others has been proven which highlighted the hybridization power and efficiency and its suitability for controlling the temperature of medical oven.
Keywords: Modeling, medical oven, PID, FLC, NN, ANFIS

INTRODUCTION

The investigation for accurate and efficient automation that capable of serving the temperature control of sensitive biological and medical applications pushed us to searching for an effective and suitable controller to meet these requirements. The rapid evolution of technology and science increasing the requirements for a precision and stable control of system temperature in every field (1) .

Due to the wide deployment of temperature applications in the world, the problem of temperature control has become a major consideration in most of the industrial applications (2), especially in the medical and biological applications. The medical and biological ovens take a special prominence for their sensitive requirements of a precise control where the traditional techniques does not provide the required control accuracy; such ovens need highly adapted controllers to ensure a high quality and safety production (3).

Artificially controlled systems have wide diffusion in practically all of engineering applications where the control modules are primal in explaining number of phenomena as in numerous biomedical and biological systems (4). Diverse strategies were applied on temperature system controls, such as PID, NN, FLC and others which are widely used in controlling temperature systems (5).

A PID based NN controller for heating system was proposed (6), where the features of uncertainty, large inertia and also delay and varying time in the thermal system can't be controlled using traditional PID, The biological immune control system characterized by self adaptability and robustness so a combination of biological immune and self-learning NN ability with conventional PID were made to get a better performance than the individual PID.

A FLC was developed to maintain the temperature and the humidity at constant values and also for fast recovery from disturbance of biomedical lab oven used for pathogens elimination (7).

A Fuzzy Neural controller for controlling the temperature of industrial furnace produced [8], it designed as two stages, the first one determine the controls variables, while the second adjusts the incoming variables from the first stage, this strategy make the extraction and reducing of MFs more easy.

In this paper a lab oven applicable on medical process modeled first, two ovens with different Transfer Functions (TF) used here, the first one used for biological experiments while the second can used for medical and biological applications. The complete heating system simulated in MATLAB Simulink, the schematic block diagram shown in fig. (1). A different controllers where designed here starting with the classical PID controller, proceeding to intelligent controllers which include Artificial Neural Network (ANN), Fuzzy Logic Controller (FLC) and the hybrid Neuro- Fuzzy controller ANFIS type, a comparison between these different controllers were made and the optimum one was chosen.

2. MODELING OF MEDICAL OVEN

The mathematical model for the Lab Oven was derived depending on heat transfer equations [9, 10], and the Lab Oven design features which is a combination of convection and radiation, as follow:

Starting from the heat balance equation [11],

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

Accumulated Heat = Input Heat − Lost Heat, in (kJ)

$MC_p \frac{dTo}{dt} = Q_{in}(t) - (Q_{conv} + Q_{rad})$ ……………… (2)

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

The thermal resistance R and thermal capacitance C are defined as:

$R = \frac{1}{h\,A}$ ………………. (4)

$C = MC_p$ ………………… (5)

Therefore, by substituting eq (4) and eq (5) in eq (3) we get:

$\frac{dTo}{dt} = \frac{1}{RC} [RQ_{in}(t) - (T_{wall} - T_{air})]$ ……………………. (6)

At steady state:

$T_o = T_{wall} - T_{air}$ ……………………….. (7)

That's lead to the eq:

$RC \frac{dTo}{dt} = RQ_{in}(t) - T_o$ ……………………….. (8)

Let, R=K, $To = x$ and R C = τ the time constant, substitute in eq (8):

$\tau \frac{dx}{dt} + x = KQ_{in}(t)$ ……………………….. (9)

Take Laplace for eq(9):

$\tau S X(S) + X(S) = KQ_{in}(S)$ ………………………… (10)

The temperature represents the output of Lab Oven after delay so, let:

$y = x(t - \tau_d)$ ………………………….. (11)

Where, τ_d is the time delay.

Take Laplace for eq(11) to get:

$Y(S) = X(S)e^{-\tau_d s}$ ………………………………. (12)

Finally, the Lab Oven transfer function is found from the relation ($G(S) = \frac{output}{input}$) [12] which yield:

$G(S) = \frac{K}{(\tau\, s+1)} e^{-\tau_d s}$ ……………………………….. (13)

3. SOFT COMPUTING TECHNIQUES

3.1. Neural Network

There are a number of NN types each has a specific architecture and can trained by one of the several training approaches [13]. Typically, a multilayer network consist of an input layer, hidden layer (or layers) and an output layer, the neurons output is given by the eq (14)

$Y_i = g_i(\sum_{j=1}^{n} W_{ij}\, X_j - \theta_i)$…………………………….. (14)

Where, Y_i is the neuron output, g_i is the activation function, W_{ij} is the weight, X_j is the neuron input and θ_i is the bias (14).

A feed forward NN used here with a back propagation training approach for weights updating. The NN controller has one input (the error) which is the difference between the set point and the actual oven temperature, one output (the control signal). The network has two layers with 10 neurons in the hidden layer for the first plant and 15 neurons for the second plant (the Lab Oven).

3.2. Fuzzy Controller

The linguistic rules are the fundamental part of every Fuzzy controller, where the controller action defined by the created rules (5). A two inputs one output Fuzzy controller designed here, with a combination of three trapezoidal and triangular input Membership Functions (MFs) and three triangular output MFs.

The Mamdani-type Fuzzy Inference consists of four basic parts: input Fuzzification, rule base, rule aggregation and defuzzification (14), the Fuzzy statement based if-then described as:

$$IF\ (e)\ is\ A_i\ AND\ (de)\ is\ B_i\ THEN\ (c)\ is\ C \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (15)$$

Where, e and de are respectively the error and change in error represents the FC inputs, c is the control signal while; A_i, B_i and C are the linguistic variables referred to Negative (N), Positive (P) and Zero (Z) in the designed controller.

3.3. ANFIS

The adaptation based essentially on the learning phase, which is a characteristic feature of ANFIS (15). The integration of NN and Fuzzy Logic (FL) give the advantages of both technologies. The ANFIS architecture as indicated in fig. (2), the 1st order Takage-Sugeno ANFIS controller designed here to have two inputs (e and de) and one output, each input consist of three Triangular MFs consequently, it construct of nine rules with linguistic sets of Negative (N), Zero (Z) and positive (P). The Hybrid algorithm is the used learning technique for data training.

Typically, the ANFIS mechanism has two inputs and one output based on the common IF-THEN Sugeno rule:

$$IF\ e\ is\ A_i\ AND\ de\ is\ B_i\ THEN\ R_j = k_{0j} + k_{1j} + k_{2j} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ (16)$$

Where, R_j is the output, j is the rules number and k is consequent parameter. The ANFIS architecture has five basic layers function as (14):

Layer1 (Fuzzification layer): This layer generates the MFs, eq. (17) represent the triangular MF,

$$O_{1i} = \mu(x) = max[min(\frac{x-a}{b-a}, \frac{c-x}{c-b}), 0] \quad \ldots\ldots\ldots\ldots\ldots\ldots.. (17)$$

Where, O_1 is the layer output, x is the input and (a, b, c) is the triangle parameters.

Layer2 (Rules layer): The firing strength is generated here which present the rules input space,

$$O_{2i} = \Pi_{i=1}^{n} O_{1i} = w_i \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (18)$$

Where, n is the number of rules.

Layer3 (Normalization layer): This layer normalizes the layer2 outputs,

$$O_{i3} = \frac{w_i}{\sum_{i=1}^{n} w_i} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (19)$$

Layer4 (Defuzzification layer): calculates the rules weighted consequent parameters,

$$O_{i4} = O_{i3}(k_{0i} + k_{1i}e + k_{2i}de) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots.. (20)$$

Layer5 (Summation layer): calculates the overall output of the ANFIS,

$$O_5 = \sum_{i=1}^{n} O_{i4} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (21)$$

The ANFIS learning algorithm is a hybrid which is a combination of two parts (16):

1- Forward pass to calculate the output (consequent parameters) till layer4 by the Least – Square algorithm.
2- Backward pass to calculate the input MFs parameters (premise parameters) using the steepest descent algorithm.

4. SIMULATION RESULTS

The control of oven temperature implemented using two different ovens transfer functions, the oven mathematical model represented by a first order with dead time as indicated in section 2.

The first oven TF and due to its specifications represented by two poles identified experimentally as [4]:

$$G_1(s) = \frac{3.6}{(556s+1)(61s+1)}$$

While, the second oven which is a practical laboratory oven tested with four different medical applications has a first order TF with time delay as:

$$G_2(s) = \frac{0.7}{13.3s+1}e^{-26s}$$

The heating system simulated in MATLAB program, a close loop step response for the first oven is obtained with different controllers which are PID, NN, FC and ANFIS controller. For the designed PID controller, a trial and error method was used for PID parameters optimization which gives an optimum response with this controller. The designed controllers compared together as indicated in fig.(3) which show the robustness and effectiveness of ANFIS controller over the others, this comparison more clarified in table (1).

After the clarification of the ANFIS preference, the second oven were modeled and simulated, the open loop response of the oven shown in fig.(4), the close loop system simulated with different controllers to show again the ANFIS superiority over other controllers and to provide the suitable training data for the ANFIS, the sampling time is 1 second, the control signal ranges from 0 to 250 watt according to the heater limitations. The heater controlled by a TRIAC power switch using different controllers listed as, PID, NN and the ANFIS keeping the oven temperature range between the ambient (25°C) and the maximum temperature at (200°C). The oven tested with the medical applications which listed as:

1- Cell Cultures at (37.5°C)
2- Wet-Granulation process at (50°C)
3- Stability performance at (70°C)
4- Dry-Heat Sterilization at (200°C)

The heating system simulation results with the different controllers for the above medical applications shown in fig.(5), fig.(6), fig.(7) and fig.(8) respectively in a comparison form, the simulation results more detailed in table (2), it is obvious that with the PID controller there is an additional delay added to the open loop oven delay, and there is a peak overshoot in the 2^{nd} &3^{rd} applications besides there is a large rise time and settling time especially in the first three applications. While, the NN controller gives a better response from the previous PID controller, where there is no peak overshoot but, it's still have an additional delay and large rise & settling time. It can observed from the results that the designed ANFIS controller give a perfect results exceeds the previous controllers, where there is no additional time delay, no peak overshoot and also, optimal rise time and settling time.

5. CONCLUSIONS

A two different ovens transfer functions are used in this research, one is a second order and the other is a first order with time delay, both can be used for medical and biological applications. A different types of controllers were designed here including the conventional PID and intelligent NN, FLC and the hybrid ANFIS. The simulation results explain well that the hybrid ANFIS is the best and the most suitable for sensitive medical applications which give an excellent and efficient performance getting over the disadvantages of PID and intelligent NN and FLC, it is fast and easy in implementation saving in that the time and efforts.

6. REFERENCES

1. Lin H., Wei L., Zikun N., (2009), "Development of PID Neural Network Control System for Temperature of Resistance Furnace", IEEE, International Forum on Information Technology and Applications, pp. 205-208.
2. Likong Li Z., Guangxiang He L., (2009), "Analysis of Heating Furnace Temperature Control System Based on Expert Fuzzy Control", IEEE International Conference on Measuring Technology and Mechatronics Automation, pp. 542-545.
3. Zhao Z, Qian M., Hong F., Long L., (2010), "Design of Temperature and Humidity Intelligent Monitoring System", IEEE International Conference on Electrical and Control Engineering, pp. 782-785.
4. Ribeiro T. R., Augusto J. S., (2010), Ibersensor Lisbon Portugal.
5. Wei J., (2010), "Research on the Temperature Control System Based on Fuzzy Self – Tuning PID", IEEE International Conference On Computer Design And Applications, Vol. 3, pp. 13-15.
6. Peng D., Zhang H., Huang C., Xia F., Li H., (2011), "Immune PID Cascade Control Based on Neural Network for Main Steam Temperature System", IEEE, World Congress on Intelligent Control and Automation, pp. 480-484.
7. Harbour W. D., Martin D. W., (2006), "Development of a Fuzzy Logic Control System in Matlab for an Air Impingement Oven", IEEE, pp. 319-324.
8. Peng X., Mo Z., Xie Sh., (2012), "Research and Application on Two-Stage Fuzzy Neural Network Temperature Control System for Industrial Heating Furnace", JOURNAL OF COMPUTERS, Vol. 7, No. 2, pp. 433-438.
9. Holman J. P., (2010), "Heat Transfer", Tenth edition, Americas, New York, McGraw-Hill, pp. 725.
10. Cengel Y. A., (2002), "Heat Transfer A Practical Approach", Second edition, pp. 853.
11. Al-Araji A. S., (2014), "Applying Cognitive Methodology in Designing On-Line Auto-Tuning Robust PID Controller for the Real Heating System", Journal of Engineering, Vol. 20, No. 9, pp. 43-61.
12. Ogata K., (2010), "Modern Control Engineering", Fifth edition, One Lake Street, Upper Saddle River, New Jersey, Prentice Hall, pp. 894.
13. Fernandez de Canete J., Gonzalez-Perez S., del Saz-Orozco P., (2008), "Software Tools for System Identification and Control using Neural Networks in Process Engineering", World Academy of Science, Engineering and Technology, pp. 59-63.
14. Negnevitsky M., (2005), "Artificial Intelligence A guide to Intelligent Systems", Second edition, Britain, Addison-Wesley, pp. 415.
15. Bindu H., Mary A., Jegan, (2012), "U-Tube Manometer Calibration using ANFIS", International Journal of Computer Applications, Vol. 49, No. 20, pp. 13-17.
16. Vieira J., Dias F. M., Mota A., (2004), " Artificial neural networks and neuro-fuzzy systems for modeling and controlling real systems: a comparative study", Elsevier, pp. 265-273.

Table (1): The simulation response comparison for the different controllers

controller	tr (sec.)	Mp	tp (sec.)	ts (sec.)
PID	148	0.16	225	390
Neural	248	0.05	275	350
Fuzzy	95	0.04	98	110
ANFIS	60	0.001	78	80

Table (2): The response time specifications comparison for the three controllers.

Cell Cultures	PID	235.3742	—	—	531.8
	NN	220.156	—	—	482.5
	ANFIS	23.5864	—	—	86
Granulation Process	PID	277.43	320	1.076	429
	NN	178.3687	—	—	416
	ANFIS	30.4499	—	—	112
Stability performance	PID	186.1543	227	6.7708	426.47
	NN	184.7429	—	—	414.1
	ANFIS	20.3726	—	—	81
Dry-Heat Sterilization	PID	54.6479	—	—	189
	NN	38.9	—	—	144.2
	ANFIS	29.2229	—	—	134.555

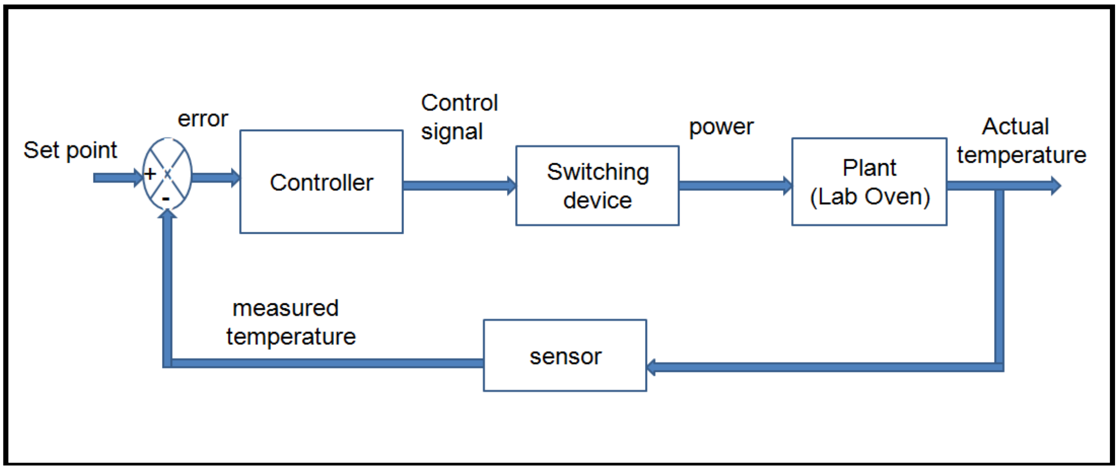

Fig. (1): Schematic block diagram of the controlled heating system.

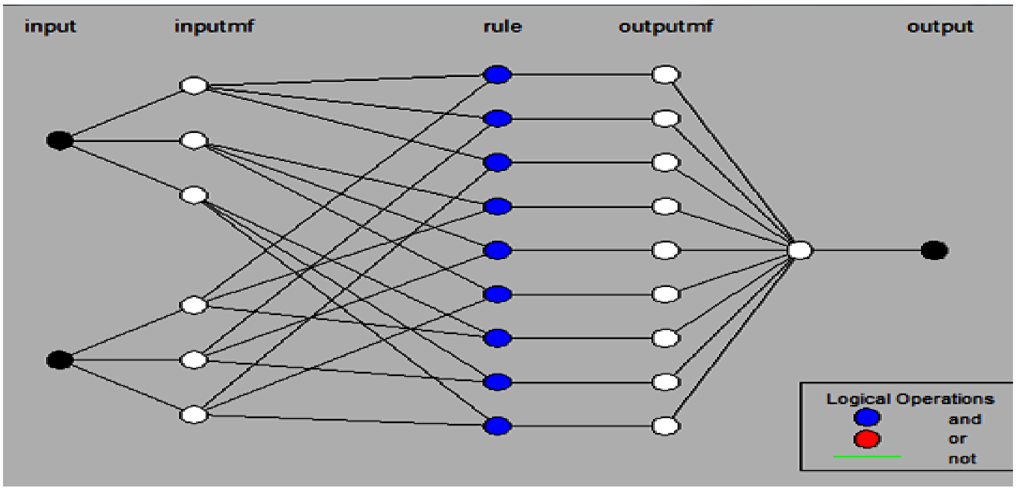

Fig. (2): The designed ANFIS architecture.

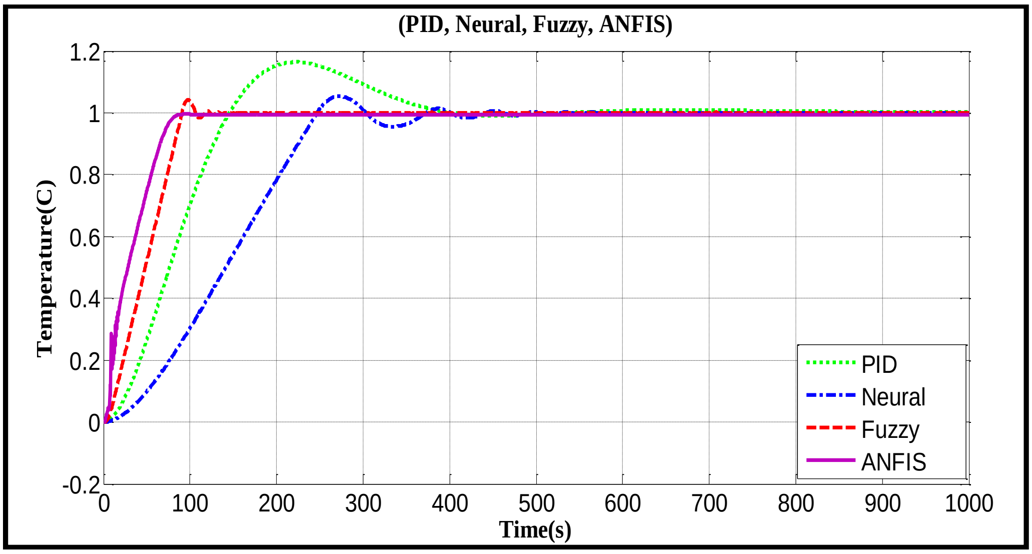

Fig. (3): The system step response for the different controllers of the 1^{st} oven.

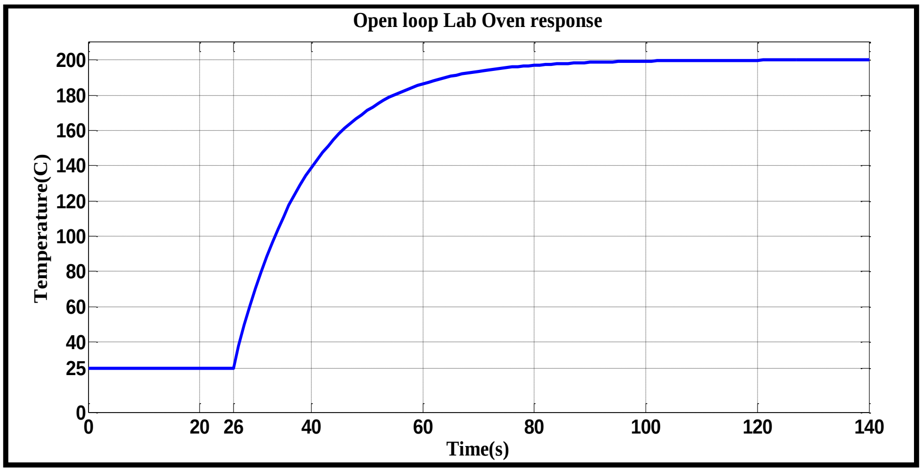

Fig. (4): The open loop TF response of the practical lab oven.

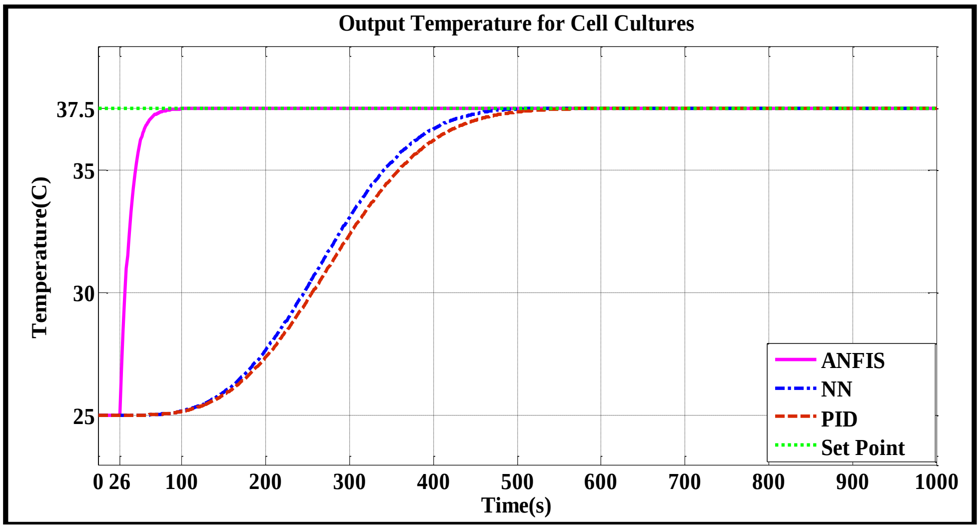

Fig. (5): The heating system response with PID, NN & ANFIS controllers for Cell Cultures.

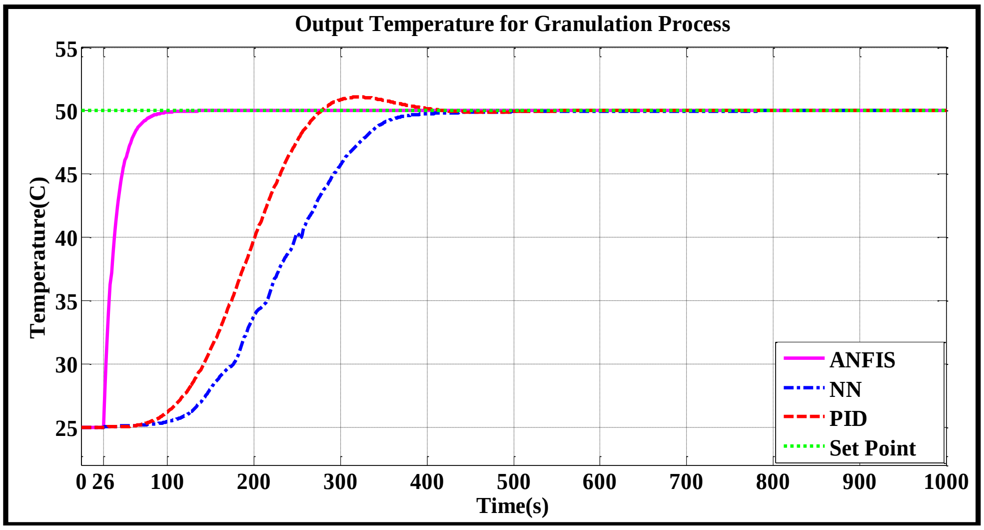

Fig. (6): The heating system response with PID, NN and ANFIS controllers for Granulation process.

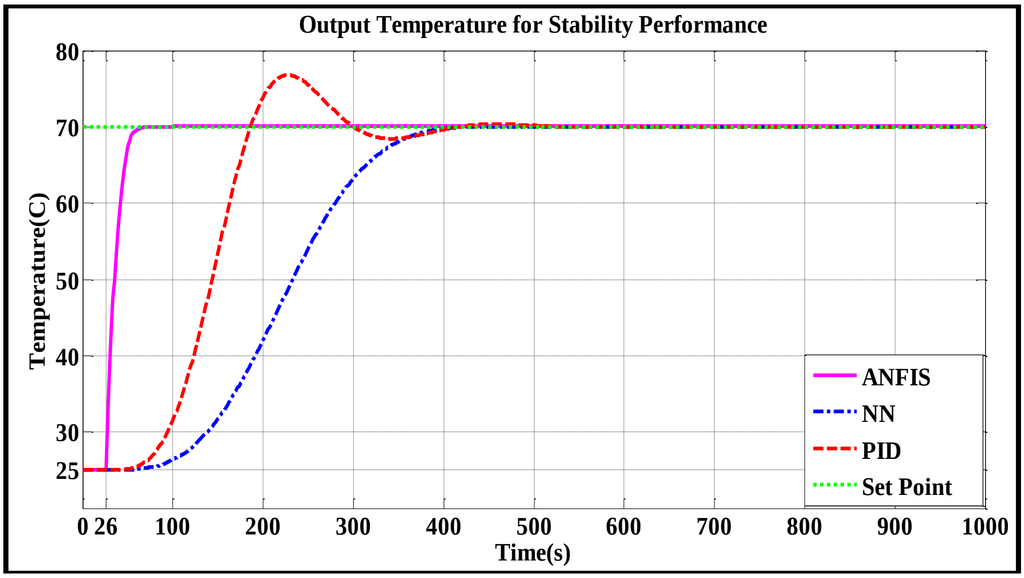

Fig. (7): The heating system response with PID, NN and ANFIS controllers for Stability performance.

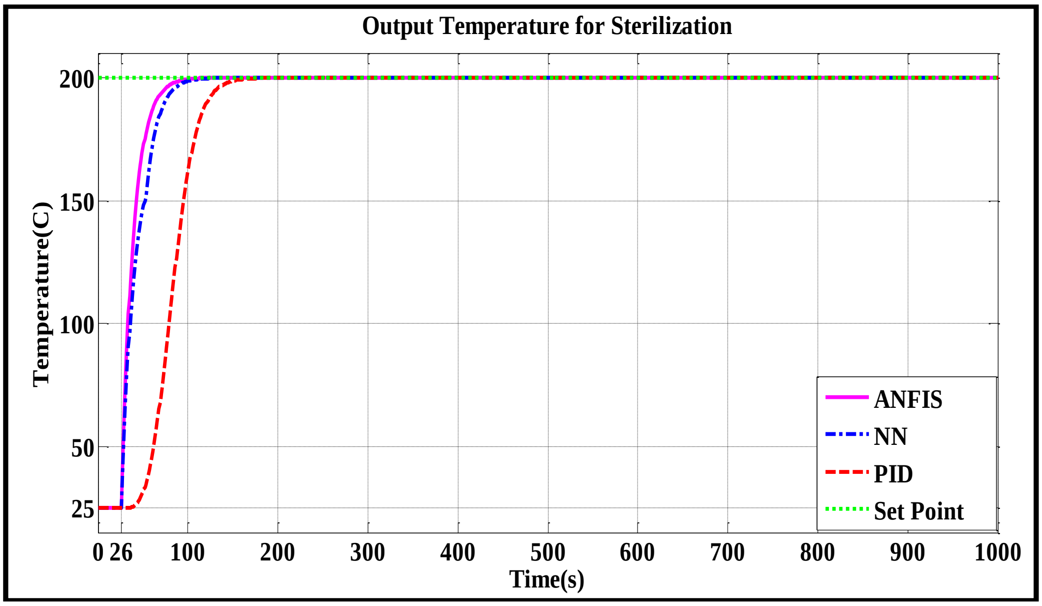

Fig. (8): The heating system response with PID, NN and ANFIS controllers for Sterilization.

السيطرة على درجة حرارة فرن طبي بالاستناد على تقنيات الحوسبة الذكية

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الخلاصة:

أنواع مختلفة من المسيطرات قد تم تصميمها في هذا البحث لغرض السيطرة على درجة حرارة الفرن الطبي. و هذه المسيطرات تتمثل بالمسيطر التقليدي التناسبي التكاملي التفاضلي و المسيطرات الذكية مُمثلة بمسيطر الشبكة العصبية و مسيطر المنطق الضبابي و مسيطر النظام التكيفي العصبي الضبابي الاستدلالي الهجين. لقد صُممت هذه المسيطرات باستخدام برنامج MATLAB الاصدار R2012a-7.14 وبواسطة كُلٍ من M-file و Simulink و باستخدام فرنين مختبريين بنموذجين رياضيين مختلفين. و قد أُجريت مقارنة بين هذه المسيطرات المُصممة بدءاً باختبار الاستجابة لدرجة واحدة بالنسبة للفرن الاول, وثانياً لدرجات حرارة مختلفةٌ لأربع تطبيقات طبية بالنسبة للفرن الثاني. وبذلك فان تفوق المسيطر الهجين على باقي المسيطرات قد تم اثباته حيث اثبت قوة التهجين و كفائته و ملائمته للسيطرة على حرارة الفرن الطبي.