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Application of Artificial intelligent techniques to temperature control in automated home heating

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ABSTRACT: *Temperature control in system such as home heating system is major thing to be considered in day to day life. Artificial intelligence (AI) has now become a day to day trend in the world at large and its application has improved technology as a whole. This paper presents different approaches to the application of AI techniques to household appliances, heater system to be precise. In this study, consideration was given to the heating system or temperature regulator system for household uses. The system was design to regulate the indoor temperature by comparing the differences between the outdoor and indoor temperature. Matlab/Simulink has been used for the design of this system. Three different AI techniques were considered in this study, these include the artificial neural network (ANN), Neuro-Fuzzy Logic (NFL) and the Fuzzy Logic (FL) techniques for controller structures. Performance analysis carried out showed that all the three AI techniques produced similar performances, however the regulated values for temperature and heat cost varied slightly for them, the ANN technique was seen to regulate the indoor temperature better but at a slightly higher cost than the other techniques.*

KEYWORDS*: AI, Smart Home, Heating System, Fuzzy Logic, Neuro-Fuzzy Logic, Artificial Neural Network.*

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I. INTRODUCTION

One definition of an automated and networked home is "An automated and networked home is one in which every appliance can be remotely managed from anywhere on the Internet with a simple Web browser, (Gunasekaran, 2016).

With the advancement of technology, automation has become part of our lives. A home is usually the most occupied place in any culture. Areas in the home that are usually occupied by people, such as the living room and bedrooms need to be maintained within habitable temperature ranges. These issues become more pertinent in areas of the home that are occupied by infants. Adults could possibly find their way around "thermal discomforts", but infants may not. Other areas of the home that are used as storage areas for perishable food items also need to be thermally regulated in order to prevent accelerated decay of such items. This makes it necessary the need for a Temperature Control System within the home, (Adamu et al, 2018).

Comfortable home automation system provides a large number of services which can broadly classified into following four categories: 1) Management of appliances 2) Remote controlling of appliances 3) Efficient utilization of home resources 4) Enhancing home security. Comfortable management includes automatic adjustment of AC (air conditioning) setting, fan regulation setting etc. Remote controlling services include accessing devices from remote location and setting them ON/OFF. Efficient utilization includes running the home appliances at their optimal setting (setting at which we get the required output at minimum cost), (Nair and Mohan, 2016).

The recent techniques of artificial intelligence have found application in almost fields of the human knowledge. However, a great emphasis is given to the accurate sciences areas; perhaps the major expression of the success of these techniques is in engineering field. Fuzzy and neural networks are two types of AI techniques. These two techniques neural networks and fuzzy logic are many times applied together which is called neuro-fuzzy for solving engineering problems where the classic techniques do not supply an informal and accurate solution, (Doaa and Hanaa, 2016).

AI is a branch of computer science that is able to analyze large scale data. ANNs, Neuro-Fuzzy techniques, and FLC are types of AI techniques. ANN's can be used to solve complex problems where noise immunity is important. Two methods of ANN training which are supervised training and unsupervised training. Supervised training needs training set where the input and the desired output of the network are provided for several training cases, while unsupervised training requires only the input of the network, and ANN is supposed to classify the data properly, (Doaa and Hanaa, 2016).

FL is commonly used in control systems. To overcome system uncertainty and parameter variations, the fuzzy logic controller is used to model the control objective based on human knowledge, understanding the system responses so there is no need for an obvious mathematical model of the system dynamics. A fuzzy controller is a system which works on numerical data and converts it into a symbolic form through a data base (fuzzification). Logic of decision-making (rule base) is implemented, thus it is possible to provide a symbolic answer which must be converted into a numerical data (defuzzification), (Lafont and Balmat, 2002).

Neuro-Fuzzy is a kind of ANN that is based on Takagi–Sugeno fuzzy inference system. Since it combines both neural networks and fuzzy logic principles, it has potential to capture the benefits of both in a single framework. Its inference system corresponds to a set of fuzzy IF–THEN rules that have learning capability to estimate nonlinear functions. Hence, Neuro-Fuzzy is considered to be a universal estimator (Coelho et al., 2005).

A. Review of related works

(Bature et al, 2013) carried out research on the design and prototype implementation of an Arduino based real-time home control system that can be used to control and monitor home appliances remotely via the Internet. In their work, remote controlling and monitoring of four devices: TV, clothes washer, lamp, and Fridge were achieved by using two applications, mobile application and web application, which were developed from scratch.

(Kharat et al, 2020) worked on an IoT based AI system, the aim of their work was to present the appliance of AI system within the IoT. The authors in (Johare et al, 2022) also worked on smart home automation system using advanced embedded system platforms with AI and IoT. An automated water head controller for domestic application was also developed by (Vema, 2014).Temperature control in closed loop system and its domestic advantages was part of the basis of the works of (Schoning et al, 2022) and (Evans et al, 2014), according to their work, Control Systems, particularly closed-loop control systems (CLCS), are frequently used in production machines, vehicles, and robots nowadays. CLCS are needed to actively align actual values of a process to a given reference or set values in real-time with a very high precession. We have identified the knowledge gaps existing in the reviewed related works and have carried out research to apply artificial intelligent techniques to control temperature in automated home heating.

II. MATERIALS AND METHODS

The materials used in this study include Matlab/Simulink software, ANN tool box, Fuzzy logic controller tool box, Neuro-Fuzzy logic controller tool box, PID controller scheme.

A. METHODS

The methods used in achieving this research work involves 5 steps, step 1 involves the characterization of AI techniques, step 2 deals with the design of AI based controllers, step 3 carries out the design of the AI based smart home heating system with AI controller techniques, step 4 deals with the testing/training of the AI controller techniques and application to the smart home heater, step 5 involves a performance analysis of the heating system using the controllers, step 6 validates the results and compares the performance of the techniques, this is illustrated in Fig.1,

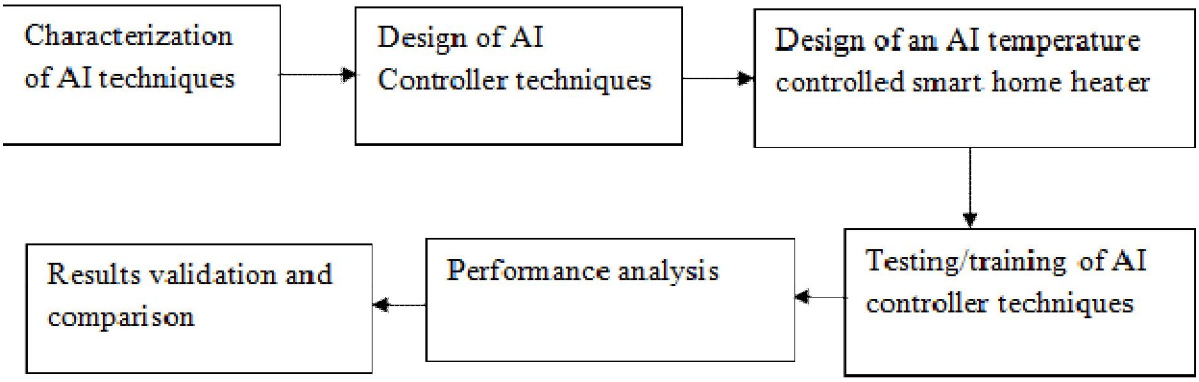

Fig. 1: Block diagram of the research work

a. Characterization of AI techniques

AI techniques can be most characterized into:

i. *Artificial neural network*
ii. *Neuro-fuzzy logic*
iii. *Fuzzy logic*

The characterization will be based on their intelligent structures, learning ability and how much they are adaptive to system control.

b. Artificial Neural Network

The AI technique uses the learning process for any controller system in which sets of inputs and output are involved. The ANN technique is unaware of the system structure in which it is to control. A set of inputs and output from the system control are being used to learn the ANN controller for several iterations, Fig. 2 shows the block diagram of a typical ANN control process. The system controller inputs are feed to the ANN for training, after which the trained ANN controller is used to control the system. ANN undergoes this learning process to understand the relationship between the input and output data, once the learning process is complete, the ANN can provide the accurate output for an input variable without knowing the system formation.

Fig. 2: ANN learning process between input and output variables

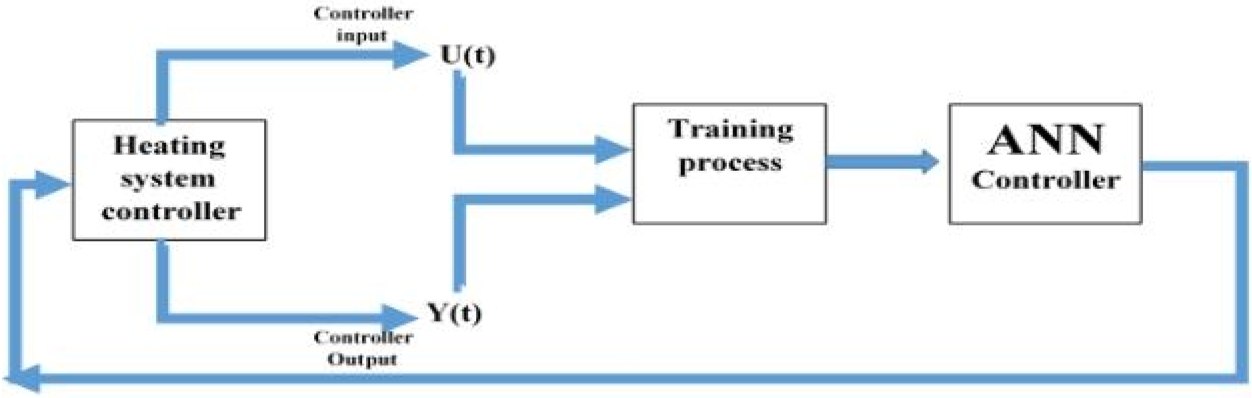

Fig. 3: ANN design technique

i. ANN model building

A neural network learns from patterns of data and tries to make predictions as accurately as possible. Assume that we already have a set of p data pairs containing the variables and the results, $(x^{(1)}, t^{(1)}, (x^{(2)}, t^{(2)}), \ldots, (x^{(p)}, t^{(p)})$ where $x^{(i)}$ input is value and $t^{(i)}$ is the target value for $i = 1, 2, 3, \ldots,$ p. A neural net F will be built so that ideally,

$$Fx^{(1)} = t^{(i)} \qquad (1)$$

Let $y^{(i)}$ denote the output of the neural net so that

$$y^{(i)} = F\left(x^{(1)}\right) = t^{(i)} = y^{(i)} + \vec{\varepsilon_i}) \qquad (2)$$

where ϵ_i is error

c. Neuro-Fuzzy logic (NFL)

The NFL AI technique makes use of membership function in classification of its inputs and outputs before training. Like ANN, it is unaware of the system structure and properties in which it is to control. Consideration will be given to a multi-input, single-output dynamic system whose states at any instant can be defined by "n" variables, $X_1, X_2, \ldots X_n$. The control action that derives the system to a desired state can be described by a well-known concept of "if-then" rules, where input variables are first transformed into their respective linguistic variables, also called fuzzification. The whole working and analysis of fuzzy controller is dependent on the following constraints on fuzzification, defuzzification and the knowledge base of a Fuzzy logic controller, which give a linear approximation of most FLC implementations. Fig. 4 shows the NFL architecture,

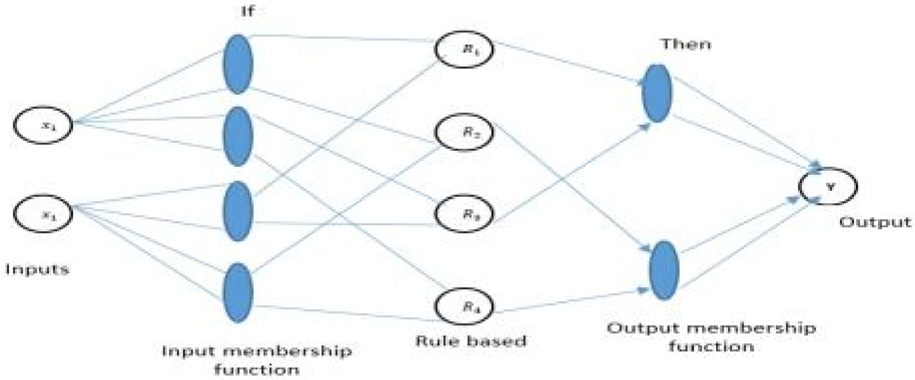

Fig. 4: Architecture of four rule fuzzy controller from neural networks point of view

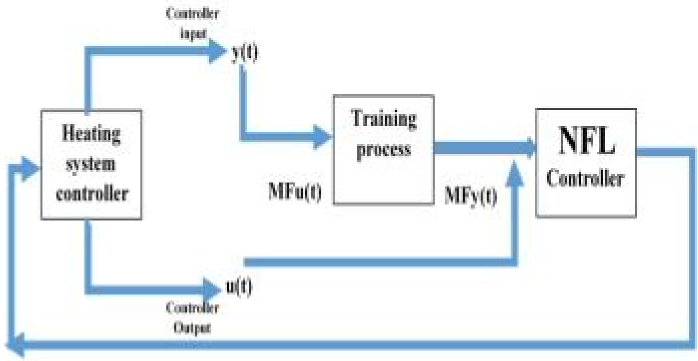

Fig. 5: Block diagram of the NFL learning system

i. NFL model building

A neural network learns from patterns of data and tries to make predictions as accurately as possible. If a set of p data pairs containing the variables and the results, $(x^{(1)}, t^{(1)}, (x^{(2)}, t^{(2)}), \dots, (x^{(p)}, t^{(p)})$ where $x^{(i)}$ input is value and $t^{(i)}$ is the target value for $i = 1, 2, 3, \dots,$ n. then, a neural net F will be built so that ideally,

$$Fx^{(1)} = y^{(i)} + t^{(i)} \qquad (3)$$

However, typically for error E_c will be allowed, let $y^{(i)}$denote the output of the neural net so that

$$y^{(i)} = F\left(x^{(1)}\right) = t^{(i)} = y^{(i)} + \overrightarrow{E_c}) \qquad (4)$$

d. Fuzzy Logic

The fuzzy logic AI technique produces a more descriptive control technique in which the controller should be aware of the system design structure and control, it is rule based and also requires the system input and input and output variable in to form a membership function. Fig. 6 describes the fuzzy logic architecture, each input and output contains a membership functions that describes the system control in a superlative manner. The functions described by the membership function are executed by the rule based inference engine.

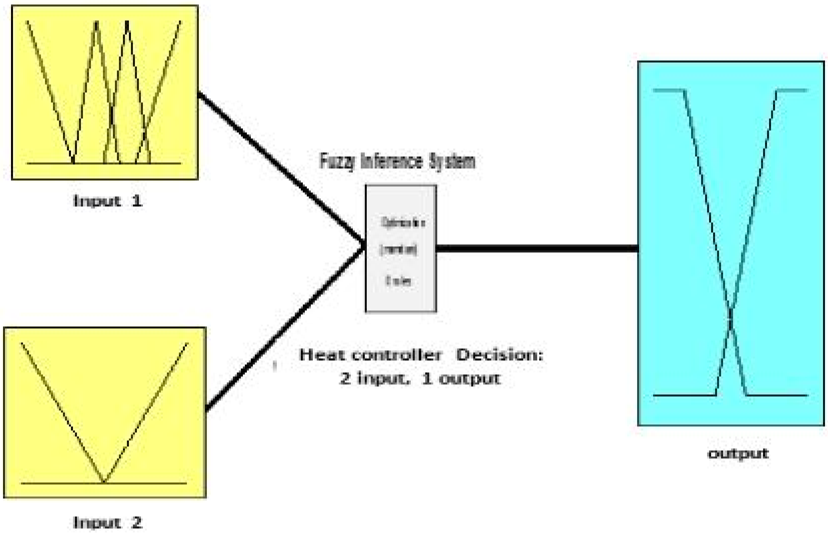

Fig. 6: Fuzzy logic architecture

i. Mathematical Description of the Fuzzy Logic System

If assumed that the behaviour of the system with input and outputs are n and y respectively, then let l, m, h indicate the membership functions in input 1, while l_1, m_1, h_1 indicate the membership functions in input 2 and, u, v be the membership function of the output U

Then,

$$U_1 = \{u, v\}$$
$$U_2 = \{l, m, h\} \qquad (5)$$
$$U_3 = \{l_1, m_1, h_1\}$$

Attaching each smart system S_{si} a fuzzy subset, A_i of U_1, U_2, U_3. If;

$$\{n_{iu}, n_{iv}\}$$
$$\{n_{il}, n_{im}, n_{ih}\} \qquad (6)$$
$$\{n_{il1}, n_{im1}, n_{ih1}\}$$

denote the number of entities to show the superlative success at each of the smart system S_{si}

respectively, then finding the membership function m_{fi} for each x in the U_i is as follows

$$m_{fU1} = \begin{cases} 1 & if\ \frac{n}{2} < n_{ix} \le n \\ 0 & if\ 0 \le n_{ix} \le \frac{n}{2} \end{cases} \qquad (7)$$

$$m_{fU2} = \begin{cases} 1 & if\ \frac{2n}{3} < n_{ix} \le n \\ 0.5 & if\ \frac{n}{3} < n_{ix} \le \frac{2n}{3} \\ 0 & if\ 0 \le n_{ix} \le \frac{n}{3} \end{cases} \qquad (8)$$

and

$$m_{fU3} = \begin{cases} 1 \quad if\ \frac{2n}{3} < n_{ix} \le n \\ 0.5 \quad if\ \frac{n}{3} < n_{ix} \le \frac{2n}{3} \\ 0 \quad if\ 0 \le n_{ix} \le \frac{n}{3} \end{cases} \qquad (9)$$

Then the fuzzy subset A_i of U_i corresponding to the S_{si} has the following form

$$f_{Ui} = \{(x, m_{fU_i}(x)) : x \in U\}, i = 1,2,3..n \qquad (10)$$

ii. Fuzzy controller design

The fuzzy logic AI technique does not require any learning rather the inputs and outputs are executed for control by a rule based system; Fig. 7 describes the fuzzy logic design procedure,

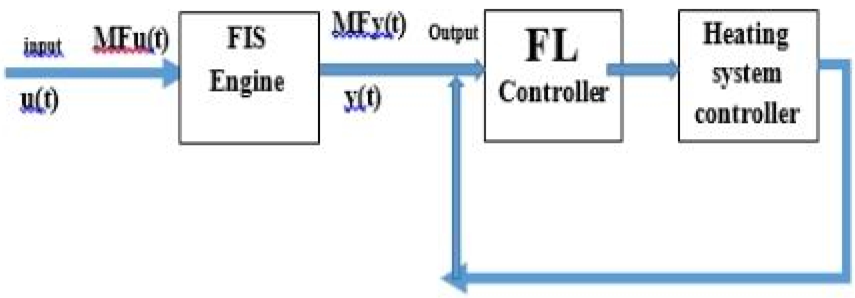

Fig. 7: Fuzzy logic design procedure

e. Design of the smart home heating system

For the smart heat controller system, the difference between the indoor and outdoor temperature measured by a thermometer will be considered in order to control the indoor room temperature and the cost of heat supplied at any particular point in time. This heating system is described using block diagram as shown in Fig. 8, the indoor temperature and heat cost are regulated using the AI controlled heating system by considering the difference between the outdoor and indoor temperature.

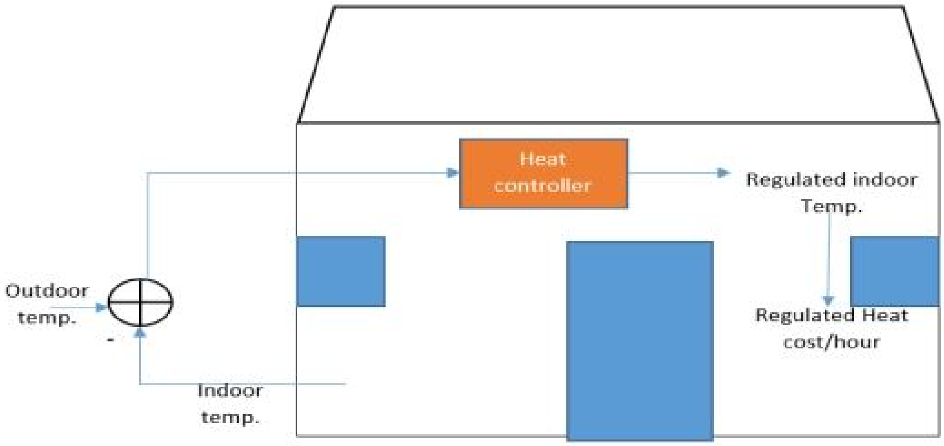

Fig. 8: Smart home thermal controller system

The Matlab/Simulink design environment can be used to implement the above described smart home heat controller system, the Simulink implementation of the system is described in Fig. 9, the thermal model makes use of the PID controller scheme so as to obtained accurate values for the system. The system described in Fig. 9 has 1 input (difference between the indoor and outdoor temperature) and 2 output (the regulated indoor temperature and the regulated heat cost).

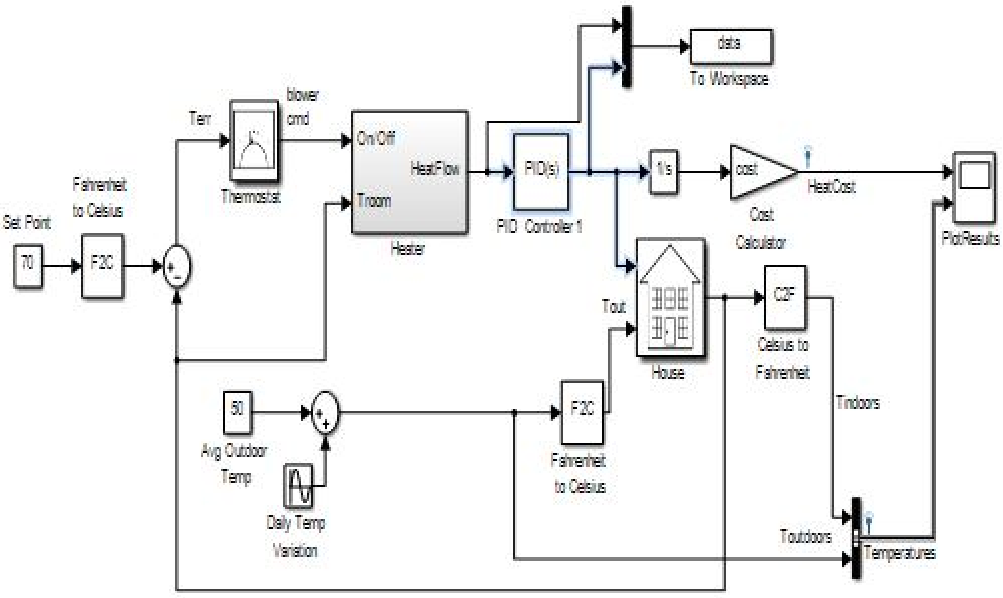

Fig. 9: Simulink implementation of Smart Heating control system

III. RESULTS AND DISCUSSION

A. System design parameters

The design parameters for the AI based system controllers are shown in Table 1, while the heater system design and PID controller parameters are shown in Table 2.

Table 1: Design parameters for the AI based system controllers

AI type	Design type	Iteration level	Number of layers	Number of nodes	Number of rules	Number of MF's	Number of input/output
ANN	AI Learning	2500	[1,5,1]	None	None	None	1,2
NFL	AI Learning	2500	None	44	10	[10,1]	1,2
FL	Design of MF	0	None	None	6	[3,3,3]	1,2

Table 2: Heater system design and PID controller parameters

Parameters	**Values**
Outdoor temp	50 ^{o}F
Indoor temperature	Varies
Set point temperature	70^{o}F
PID gains	[1, 1, 0.1]
Average hourly cost for heat	40 aira

B. Performance analysis of system

This section will compare the temperature control in the smart home heating system using the different AI controllers. The performance analysis will be carried out for 50 seconds of simulation time of which the indoor temperature is varied between 25 to 70^{o}K.

C. Indoor Temperature regulation

Table 3 presents the regulated indoor temperature on application of the AI controllers, it is observed that all three AI techniques produced the same regulated control, but with the ANN controller having a higher degree of temperature regulation, between 10 to 20 seconds of simulation time, the NFL controllers is seen to regulate at every microseconds unlike the FL controller that regulated each seconds of the simulation time, however ANN controller is seen to show a lower regulation behaviour when the indoor and outdoor temperature are fairly equal. Fig. 10 presents a plot of the regulated indoor temperature for 50 seconds of simulation time.

Table 3: Regulated temperature values for AI controllers

Time(s)	**Outdoor temperature (^{o}F)**	**Indoor temperature (^{o}F)**	**ANN regulated temperature (^{o}F)**	**NFL regulated temperature (^{o}F)**	**FL regulated temperature (^{o}F)**
1	92	64	77	72	71
2	66	36	67	62	61
3	65	32	67	62	61
4	84	42	71	66	65
5	65	42	75	70	69
6	91	54	70	65	64
7	71	56	78	73	72
8	68	53	76	71	70
9	82	42	80	75	74
10	81	36	72	67	66
11	83	50	75	74	73
12	82	35	73	72	71
13	67	51	72	71	70
14	88	60	69	68	67
15	82	51	70	69	68
16	71	26	73	72	71

17	89	48	67	66	65
18	65	34	66	65	64
19	84	70	70	69	68
20	90	42	73	72	71
21	91	46	67	65	64
22	88	53	69	67	66
23	87	48	70	68	67
24	83	48	74	72	71
25	67	50	75	73	72
26	81	46	79	77	76
27	85	44	84	82	81
28	75	48	89	87	86
29	91	66	90	88	87
30	79	53	95	93	92
31	72	68	96	94	93
32	77	61	92	90	89
33	82	44	87	85	84
34	80	52	82	80	79
35	95	69	76	74	73
36	68	43	74	72	71
37	76	41	71	69	68
38	83	49	69	67	66
39	81	67	65	63	62
40	85	46	62	60	59
41	78	50	61	59	58
42	91	27	60	58	57
43	88	38	62	60	59
44	74	31	64	62	61
45	88	33	65	63	62
46	79	48	67	65	64
47	69	45	69	67	66
48	73	63	71	69	68
49	73	35	73	71	70
50	81	33	76	74	73

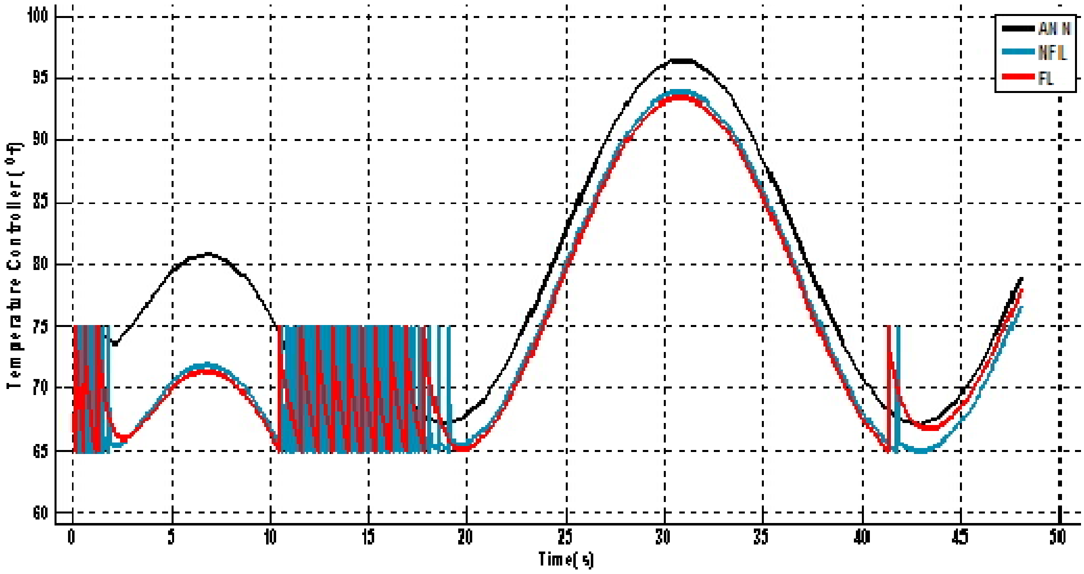

Fig. 10: Graph of regulated indoor temperature for compared AI controllers

D. Heat cost regulation

The cost regulation as indicated by the AI controllers showed that the cost regulation patterns for all controllers are the same. However the FL controller gives a lower cost regulation for the regulated temperature as shown in Table 4, the ANN controller gives a higher heat cost compared to the others. The slight cost difference is as a result of its regulated temperature within the simulation time. Fig.11 shows the graph of the regulated cost for the three AI techniques against the simulation time.

Table 4: The Regulated costs for the three AI controller methods

Time (s)	ANN cost regulation (Naira)	NFL cost regulation (Naira)	FL cost regulation(Naira)
1	0.911	0.455	0.0339
2	1.822	0.822	0.4009
3	2.733	1.0117	0.5906
4	3.644	1.9227	1.5016
5	4.555	2.8337	2.4126
6	5.466	3.7447	3.3236
7	6.377	4.6557	4.2346
8	7.288	5.5667	5.1456
9	8.199	6.4777	6.0566
10	9.11	7.3887	6.9676
11	10.021	8.2997	7.8786
12	10.932	9.2107	8.7896
13	11.843	10.1217	9.7006
14	12.754	11.0327	10.6116
15	13.665	11.9437	11.5226
16	14.576	12.8547	12.4336

17	15.487	13.7657	13.3446
18	16.398	14.6767	14.2556
19	17.309	15.5877	15.1666
20	18.22	16.4987	16.0776
21	19.131	17.4097	16.9886
22	20.042	18.3207	17.8996
23	20.953	19.2317	18.8106
24	21.864	20.1427	19.7216
25	22.775	21.0537	20.6326
26	23.686	21.9647	21.5436
27	24.597	22.8757	22.4546
28	25.508	23.7867	23.3656
29	26.419	24.6977	24.2766
30	27.33	25.6087	25.1876
31	28.241	26.5197	26.0986
32	29.152	27.4307	27.0096
33	30.063	28.3417	27.9206
34	30.974	29.2527	28.8316
35	31.885	30.1637	29.7426
36	32.796	31.0747	30.6536
37	33.707	31.9857	31.5646
38	34.618	32.8967	32.4756
39	35.529	33.8077	33.3866
40	36.44	34.7187	34.2976
41	37.351	35.6297	35.2086
42	38.262	36.5407	36.1196
43	39.173	37.4517	37.0306
44	40.084	38.3627	37.9416
45	40.995	39.2737	38.8526
46	41.906	40.1847	39.7636
47	42.817	41.0957	40.6746
48	43.728	42.0067	41.5856
49	44.639	42.9177	42.4966
50	45.55	43.8287	43.4076

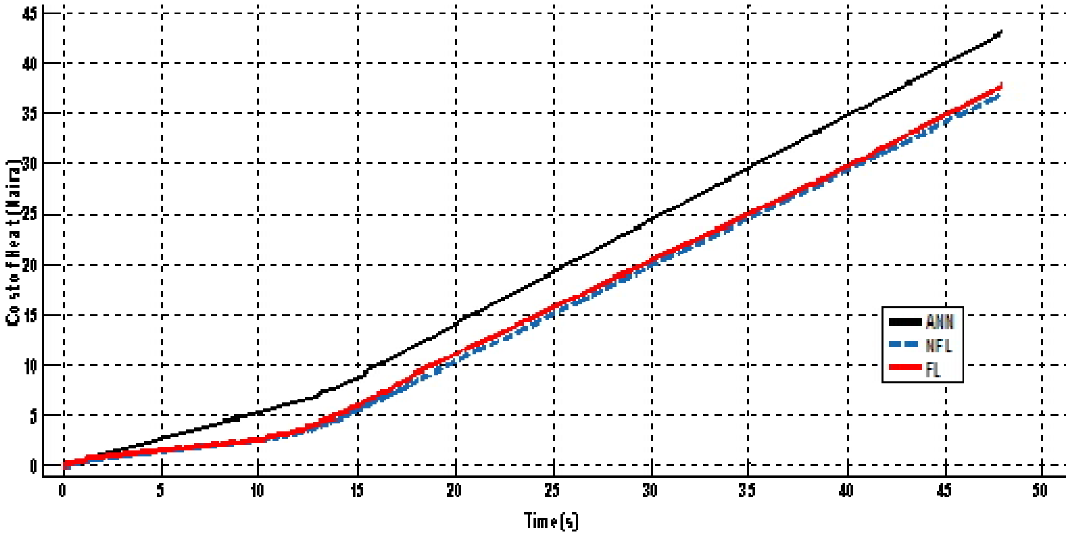

Fig.11: Graph of regulated heat cost in Naira against time

IV. CONCLUSION

The study presented different approaches to the application of AI techniques to household appliances. In this research work, the heating system or temperature regulator system for household uses was considered. The system was design to regulate the indoor temperature by comparing the differences between the outdoor and indoor temperature. Matlab/Simulink has been used for the design of this system. The artificial neural network, Neuro-Fuzzy Logic and the Fuzzy Logic techniques are the three AI techniques used for temperature control in automated home heating. The performance analysis carried out to show that all the three AI techniques produced similar performances; however the regulated values for temperature and heat cost varied slightly for them. It was observed that the ANN technique regulated the indoor temperature better but at a slightly higher cost than the other techniques.

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