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Fuzzy Logic Controller for Classroom Air Conditioner

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Abstract. In the modernized era, the air conditioners are an integrated part of comfort living especially in hot climates. They are used to control the interior spatial temperature, relative humidity, degree of cleanliness, and speed of air streaming. The automatic controllers are the key elements of the modern air conditioning systems that ensure the reliable operation, improved quality, low operation cost, and better security. Thus, the realization, design, and application of the controller systems require the exact specifications of the involved processes. In this regard, controllers based on the fuzzy logic (FL) are prospective for air conditioners due to the easy accessibility of different output levels. Furthermore, using the FL it is possible to scale and control the users' air processing demand depending on the temperature and relative humidity of the space. Based on these factors, this paper reports the design and performance evaluation of a FL based controller useful for air conditioners when implemented in the classroom setting. This FL based control system can reduce the complexity of programming thereby can be executed on general microcontrollers utilized in the control panels of classroom air conditioner. The results revealed the outperforming nature of the FL based controllers over other traditional controllers used to adjust the indoor temperature and relative humidity by air conditioners.

1. Introduction

Being nonlinear and adaptive system, the fuzzy control provides favorable performance for diverse plants with the variation of parameters. To regulate the indoor atmospheric conditions (ambient temperature, humidity level, air distribution, and circulation) the FL controllers are widely used in most of the modern air conditioning systems. The performance of these air conditioners is critically

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decided by the embedded automatic controller. Presently, for achieving the reliable operations, better qualities, low working costs, and better safety the control automation systems are diversely implemented in machineries and processes. Actually, the design, development, and ultimate performance of the implemented control systems require the detail specifications of the factory, machine, or process that needs to be regulated [1].

In recent times, the FL based control system received focused interests from both fundamental research and industrial applications perspectives. The FL based controllers are comprised of regulator and plant, where an actuator interfaces them. The interactions among all these components eventually decide the performance the controller. The performances of the controllers functioning in the several input and output variables controlled environment depend on the correlation among the design, modeling, and simulation of the local and distributed environment [2]. The main concept of FL controller is to insert an operator's expertise in its design to regulate the processes for describing the input-output correlation is using the set of fuzzy control rules linking the linguistic variables such as IF-THEN. The use of linguistic variables, estimated interpretation, and fuzzy control rules allows incorporating the human expertise in the controller design [2].The operation of the air conditioners and refrigerators are based on the removal of thermal energy (heat) from the system through the mechanisms of radiation and convection, wherein the heat pumps are used in the refrigeration cycle. Refrigerants including water, air, ice, and other chemical reagents are used to maintain such cycle. An individual air conditioners or air conditioning systems offer the humidity level control, cooling and ventilation in the entire inner space of the buildings [3]. The traditional air conditioners use only one actuator for controlling the temperature and have some limitations. To overcome this drawback, this paper proposes a new strategy wherein two actuators have been used to optimally control the temperature of the air conditioner. In this approach, the variable speed is used to operate the pump for exchanging the heat effectively [4].

The FL controllers are advantageous for air conditioners in regulating the output levels desirably. Besides, the FL controllers can scale the air conditioners demand depending on the room temperature and humidity level, allowing a user friendly functioning. On top, apart from air conditioners activation in case of either too hot or too humid, it can also regulate the temperature and humidity conditions desirably in case the room is simply merely warm and rather humid and so forth. Section below provides a critical review of some recent studies conducted on FL controllers.

Figure 1 illustrates the functioning of a typical air conditioning system. Figure 2 represents the block diagram of the proposed FL controller based air-conditioners. This system is comprised of at least two sensors one for monitoring the temperature and the other for screening indoor humidity level. Furthermore, the outdoor temperature, humidity level, and other parameters can also be monitored with other precise controllers in complex systems [5].

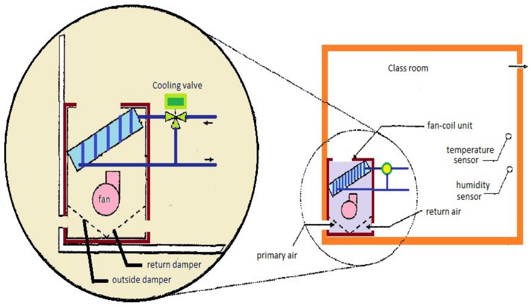

Figure 1. Working principle of s typical air-conditioner.

Several other actuators in the valve systems are possible for the indoor air quality control such as the cooling, heating, humidifying, fan speeding, returning, air supply damper's positioning, temperature and humidity adjusting, etc. Position of every actuator and its derivative as well as integral can be utilized as a controller input, thereby attaining the gain, and simulating the close loop PID control. In fact, various parts of a typical air conditioner can perform as an output to direct the humidity level and indoor temperature. By the selection of an output it is possible to construct the system model and design the FL controller to manage each of the output.

2. Basic design of an air-conditioner

Figure 2 depicts the basic design of a FL controller, which consists of four main interfaces based on the: (i) fuzzification, (ii) knowledge, (iii) decision making logic, and (iv) defuzzification. In addition, the fuzzification interface has two functions: (i) it measures the input variables values, and (ii) executes the scale mapping that transfers the input variables range into the related universes of discourse. The fuzzification interface transfers the input data into appropriate linguistic values which can be considered as the fuzzy sets labels. The knowledge base interface comprised of application information domain and the control goal of attendant. It is comprised of a database and a linguistic (fuzzy) control rule base, where the database renders the necessary descriptions [8].

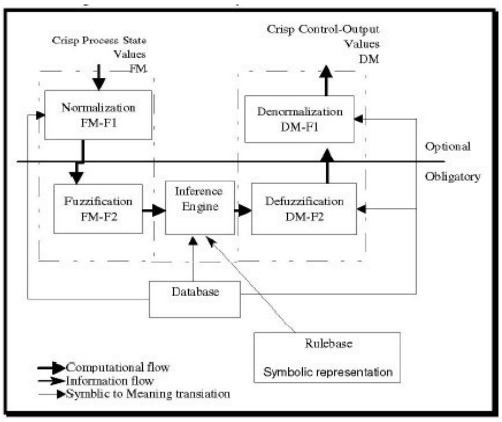

Figure 2. Basic design of a FL controller

2.1 FL Air Conditioning

During the situation of highest energy demand, the air conditioner must function similar to an ordinary control system. The air conditioner pump can perform at optimum level with full width of the control valve. During the condition of least energy demand, first the pump speed is first diminished to a moderately low level where its dynamic performance is very different compared to the control valve. In the second phase, the control valve takes over the task until the process value reach to the set point value. It is important to note that the control valve must close initially, when the actual pump speed is at its lowest level [5]. Therefore, the feedback position of the control pump and valve are vital for the operation. In the proposed system both the control valve and pump are not the actuators in the supply loop. The controller was fed with the information of the actuator operations to attain the robust control. The true position of the actuator can be obtained from the local operational network to get the real time feedback. One processor was allocated for every actuator to execute the communication with the other control unit [9].

3. Methodology

This paper used the FL controller design to improve the performance of the air conditioning system in consistent with the weather situations, which are achieved in 5 phases as depicted in Figure 3. The detail of these phases is emphasized hereunder.

Phase 1: Problem Formulation

Using air conditioners the temperature and humidity level of the air can be tuned to make them more favorable. Traditional control strategies used by the air conditioner to meet these purpose involves energy wastage and less comfort, thus cannot fulfill the exact demand of the in terms of quick adjustments of indoor temperature or humidity control. Additionally, the design of usual control system require precise mathematical model to get the optimum parameters. Thus, a novel controller for air conditioners with high efficiency, elevated conform level and energy saving is required. To resolve the existing issues, this work proposed the design of the FL based controller for air-conditioner which can regulate the class room temperature and degree of humidity depending on the desired values by measuring the exterior and interior air flow.

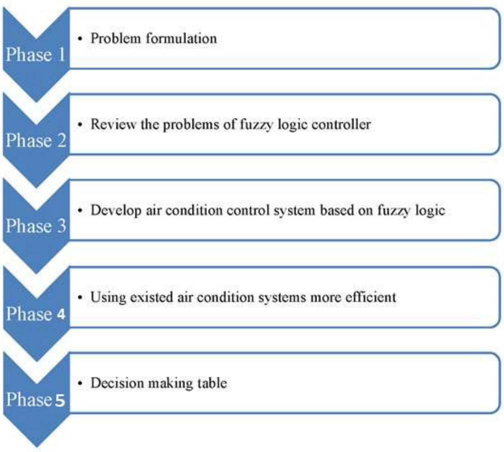

Figure 3. Flow diagram of the planning.

Phase 2: Overview on Issues Related to FL Controllers

Major issue of fuzzy control technique is related to the efficient evaluation of the proper membership function and control rule. Moreover, using traditional PID or FL it is difficult to achieve good performance in air-conditioning system since the room temperature setting is quite complex where accurate mathematical models are lacking for the control over wide frequency range. To improve the intelligence of the controller the fuzzy NN was introduced for the air conditioners. In fact, the NN can make the learning capacity related to the environmental changes very strong. Thus, to express the input-output correlations easily the fuzzy and NN are combined to get the FNN which can increase the transparency and learning capacity of the controllers. For optimum control systems, FNN controllers are used for training, wherein the training and learning processes produce better control with robust self-adaptive character control [10].

Phase 3: Development of FL Based Air Conditioning Control System

In this work, the FL controller designed for the air conditioners can adjust the classroom air temperature and humidity level via a set of input parameters as depicted in Figure 3. Two tunable dampers called return and supply air damper are used as outputs. Via sending the proper signal based on the monitoring input, set point and specific rules, the FL controller can control the opening and closing levels of the damper's vents to provide desired level of temperature and humidity. The return air damper supplies the indoor air and the supply one for outdoor air provider. By mixing the indoor and outdoor air flow in appropriate proportions specified by the FL controller, the favorable air can be obtained, pushing out via the fan with a stable speed

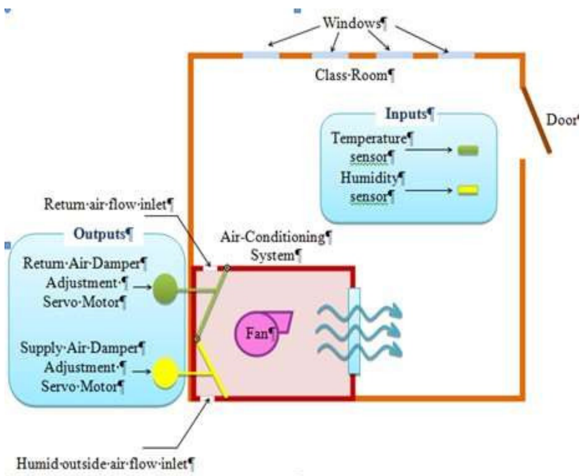

Figure 4. Air conditioners in the classroom setting.

Phase 4: Developing the System Benefit for Classroom

Presently, energy economy is one of the main quests in the modern air conditioning system, especially to those interfaced with the institutions. To get the maximum efficiency (nearly 75%) from total consumed energy of air conditioning system the innovative design of building, auditorium, indoor stadium, and halls are preferred [9]. In terms of electricity bills, the power consumptions by the air conditioners even at the domestic sectors and offices play a vital role. Thus, to keep the indoor temperature and the humidity level near to the desired values a substantial reduction in the intake of electrical energy by the air-conditioners (compressors and fans) during the uses of all accessible resources efficiently manner is necessary.

Phase 5: More Efficient Use of Existing Air Conditioners

The proposed air conditioning system requires precise thermodynamic design even if it is easy to control the indoor humidity level and temperature. Often, sufficient facilities are lacking to design an air conditioning system. Therefore, the alteration in the existing electrical and mechanical system is performed via FL for efficient usage. To attain this goal, all the actuators and sensors in the air conditioning systems must be specified and programmed using a properly designed controller for desired outputs.

Phase 6: Decision Making Table

Currently, only few controllers have been developed for performing fuzzy calculations. However, implementation of these calculations in the traditional controllers is highly time intense as well as complex. On top, it is not advocated for online applications especially in the small business sectors due to unaffordable costs. Thus, the inputs quantization and FL controllers based outputs calculations over the entire range became mandatory. These calculated outputs must be written close to the related inputs to create a decision making table for their easy implementation in a controller. The purpose of controlling must be attained via the simplistic search algorithms within this table to make the decision very fast. The accuracy of sensors and memory of controllers depends on the range of the inputs quantization which can easily be achieved via the A2D hardware or simple software codes [11].

3.1 Plant Formulas

To simulate the designed mathematical model of the classroom air conditioner, the temperature and humidity level was altered during use. The plant formulas for temperature are defined as:

$$C\frac{d\theta}{dt} = \omega_s(\theta_s - \theta) + a(\theta_s - \theta) + q_L \tag{1}$$

$$\omega_s = \omega_{s1} + \omega_{s2} \ , \ \theta_s = \frac{\omega_{s1}\theta + \omega_{s2}\theta_0}{\omega_{s1} + \omega_{s2}} * (1 - a) \quad , \quad \omega_{s1} = p_a c_p f_{s1} \ , \ \omega_{s2} = p_a c_p f_{s2} \tag{2}$$

$$\frac{\Delta\theta}{\Delta t} = \theta_{(t)} - \theta_{(t-\Delta t)} = \frac{\omega_s\left(\theta_s - \theta_{(t-\Delta t)}\right) + a\left(\theta_0 - \theta_{(t-\Delta t)}\right) + q_L}{c} \tag{3}$$

The plant formula for humidity is defined as:

$$V\frac{dx}{dt} = (f_{s1} - f_{s2})(x_s - x) + \frac{n}{pa} \tag{4}$$

$$x_s = \frac{f_{s1}x + f_{s2}x_0}{f_{s1} + f_{s2}} * (1 - b) \tag{5}$$

$$\frac{\Delta x}{\Delta t} = x_{(t)} - x_{(t-\Delta t)} = \frac{f_{s2}\left(x_s - x_{(t-\Delta t)}\right) + \frac{n}{pa}q}{V} \tag{6}$$

The estimated temperature and humidity levels using these relations were compared with the set points (the desirable values for temperature and humidity). The difference between these values and set points were sent to the controller as inputs wherein proper decisions were made based on the generated rules [13]. Table 1 describes the nomenclatures of the developed mathematical relations in the model.

Table 1. Taxonomy of mathematical formulas

Description	Unit	Value
Indoor air temperature measured by actuator	K	-
Indoor absolute humidity	kg/kg (DA)	-
Indoor air temperature at set point	K	20
Indoor relative humidity set point	K	40
Air condition output air temperature	K	-
Outdoor air temperature	K	
Air condition output air absolute humidity	kg/kg (DA)	-
Absolute humidity of the outdoor air	kg/kg (DA)	-
Overall heat capacity of air-conditioned space	kJ/K	370.44
Cooling rate of fan	(DA)	0.3
Drying rate of fan	(DA)	0.1
Room volume	m^3	10*10*2.7=270
Specific heat of air	kJ/kg K	1.3
Density of air	kg/m^3	1.006
evaporation rate of an occupant	kg/min	0.00133
number of occupants in the room	-	5
Overall transmittance-area factor	kJ/min K	9.69
Thermal load from internal heat generation	kJ/min	121.72
Air flow rate through return damper	m^3/min	-
Air flow rate through supply damper	m^3/min	-
Which is heat of air flow rate	kJ/kg K	-

3.2 Fuzzy Rules

Table 2 depicts the set of defined rules for the designed FL controller. Figure 5 and 6 illustrates the schematic diagram of the proposed air conditioning system and the working principle of the air conditioner to control the indoor temperature and humidity. The inputs and outputs details of the FL based controller are shown in Figure 7.

Table 2. the rules for the designed FL controller

No	Humidity	Humidity Rate	Temperature	Temperature Rate	Return Damper	Supply Damper
1	Very high	-	Very high	-	Fast open	Fast close
2	Very high	-	high	-	Fast open	Fast close
3	Very high	-	normal	-	Fast open	Fast close
4	Very high	-	low	Increasing	open	Fast close
5	Very high	-	low	decreasing	steady	Fast close
6	Very high	-	Very low	-	close	Fast close
7	High	-	Very high	-	Fast open	close
8	High	-	high	-	Fast open	close
9	High	-	normal	-	open	close
10	High	-	low	increasing	open	close
11	High	-	low	Decreasing, 0	steady	close
12	high	-	Very low	-	close	close
13	normal	increasing	Very high	-	Fast open	steady
14	normal	Decreasing, 0	Very high	-	Fast open	open
15	normal	Decreasing	high	-	open	open
16	normal	Increasing, 0	high	-	open	stable
17	normal	increasing	normal	Increasing, 0	open	close
18	normal	increasing	normal	decreasing	steady	close
19	normal	zero	normal	Increasing	open	steady
20	normal	zero	normal	zero	steady	steady
21	normal	zero	normal	decreasing	close	steady
22	normal	decreasing	normal	Increasing	steady	open
23	normal	decreasing	normal	Decreasing, 0	close	open
24	normal	increasing	low	-	steady	close
25	normal	Decreasing, 0	low	-	close	steady
26	normal	increasing	Very low	-	Fast close	steady
27	normal	Decreasing, 0	Very low	-	Fast close	open
28	low	-	Very high	-	Fast open	open
29	low	-	high	-	open	open
30	low	-	normal	Increasing	steady	open
31	low	-	normal	Decreasing, 0	close	open
32	low	-	low	-	Fast close	open
33	low	-	Very low	-	Fast close	steady
34	Very low	-	Very high	-	Fast open	Fast open
35	Very low	-	high	-	open	Fast open
36	Very low	-	normal	increasing	steady	Fast open
37	Very low	-	normal	Decreasing, 0	close	Fast open
38	Very low	-	low	-	Fast close	Fast open
39	Very low	-	Very low	-	Fast close	open

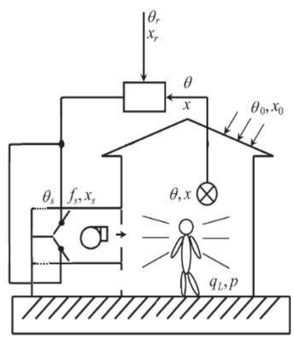

Figure 5. Schematic diagram of the proposed air conditioning system.

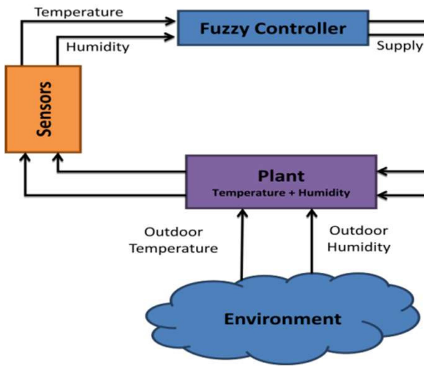

Figure 6. System block diagram

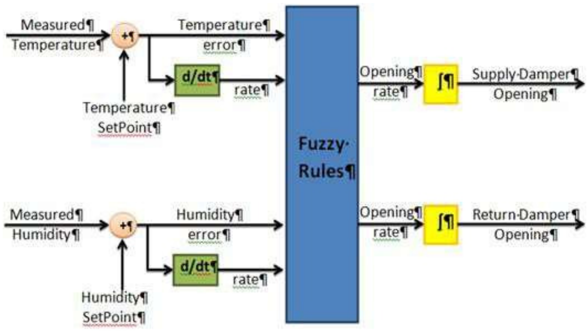

Figure 7. Inputs and outputs details of the FL based controller.

4. Results of FL Controllers

The design of an efficient and reliable air conditioner by implementing a FL based controller useful for the classroom environment was the main air of this paper which was achieved in few steps. First, a typical air conditioning system using simple actuators was designed and simulated through Matlab programming. This FL controller based air conditioner tried to use realistic conditions. Second, the Matlab based M-file was used to train the FL controller through a desired dataset. Thus, no expert knowledge was required except to assemble the desired dataset without difficulty [12]. Third, the developed FL controller was implemented for online applications wherein a Matlab code was written to substitute the controller by a decision making table. The designed M-file calculated the elements of the table which was further loaded in a simple controller memory. The air conditioner was controlled by a simple search program that was loadable in any simple controller such as AVR. Finally, the unification of these steps allowed us to achieve an efficient, reliable, and cost effective classroom air conditioner based on FL controller.

4.1 Discussion

In Fig. 8, shows the relationship of genuine room temperature and target temperature with the fan speed. The created chart shows the augmentation in target temperature will cause the fan speed to increment until 30˚C and the fan speed is steady after that as configuration to adjust to the condition. In particular, limited in Malaysia is hot consistently and along these lines, the objective temperature will not be more than 30˚C. Next, the genuine room temperature is planned with the end goal that, if the temperature rises, the fan speed will likewise increment to cool up the room in the wake of contrasting and target temperature.

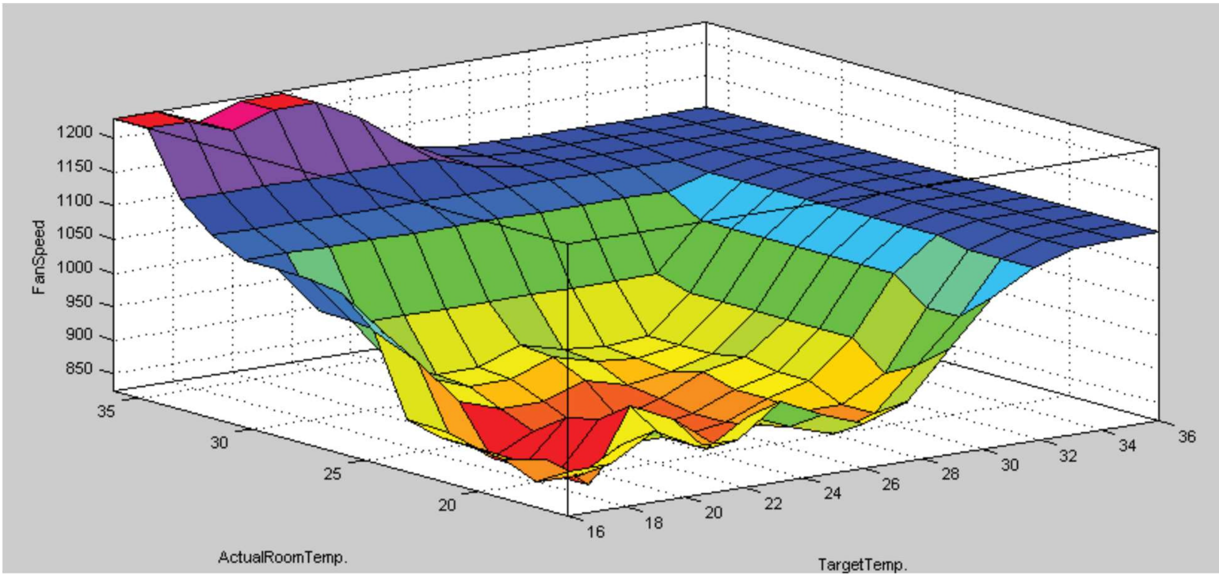

Figure 8. SV of variation of fan speed.

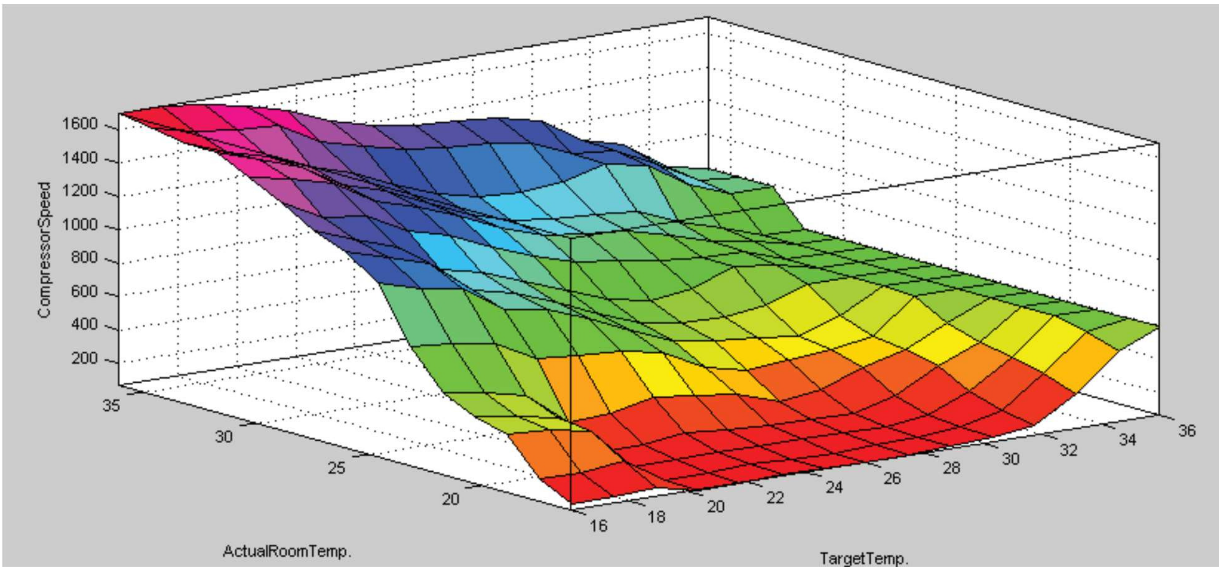

Figure 9. SV of variation of compressor speed.

Fig. 9 outlines the smooth difference in blower engine speed as per the sign changes in target temperature furthermore, genuine temperature. At the point when the sensor recognizes the continuous changes of the real room temperature with relates to target temperature, the blower speed will likewise increment what's more, the other way around. Moreover, in light of the outcomes, it very well may be supported that the use of blower engine can be enhanced in a smart manner by the planned Fuzzy Logic rules. In this manner, the effectiveness of the cooling framework is improved by decreasing the overabundance vitality utilization. In addition, Fig. 10 shows the impact of real room temperature and stickiness of the room on the fan speed. As the temperature and stickiness increment the fluffy rationale controller will react to this adjustment in inside room's condition and the fan speed will increment as needs be. The focal zone of the figure demonstrates that, in this manner the fan speed will work with not exactly a large portion of its control, which infers the decrease of intensity utilization what's more, thus, self-flexibility of the framework is accomplished.

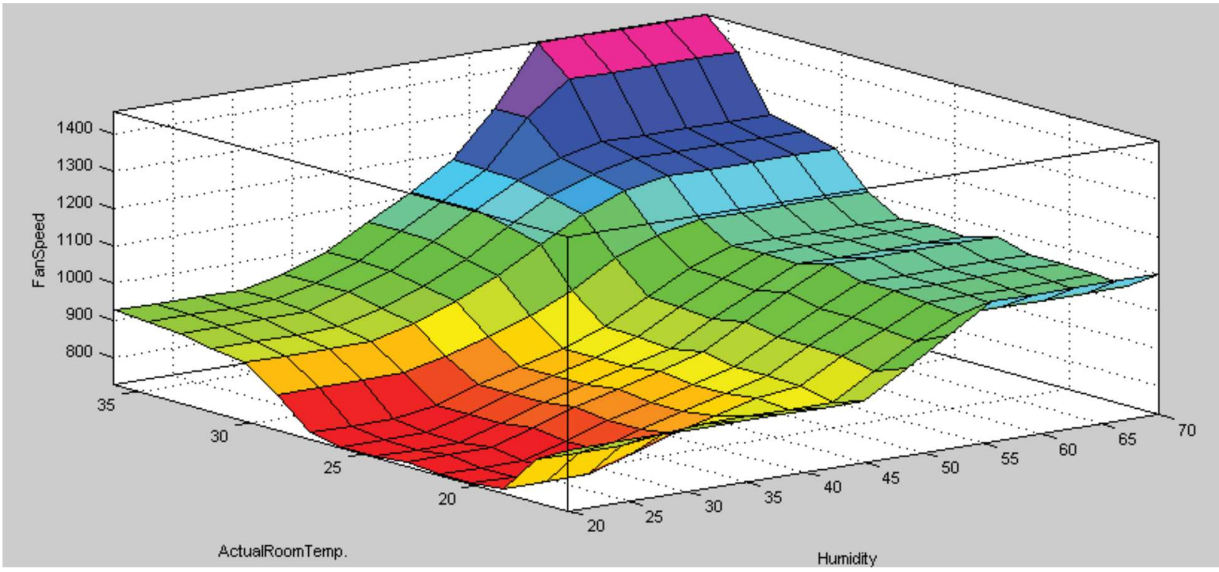

Figure 10. SV of fan speed with humidity and room temperature.

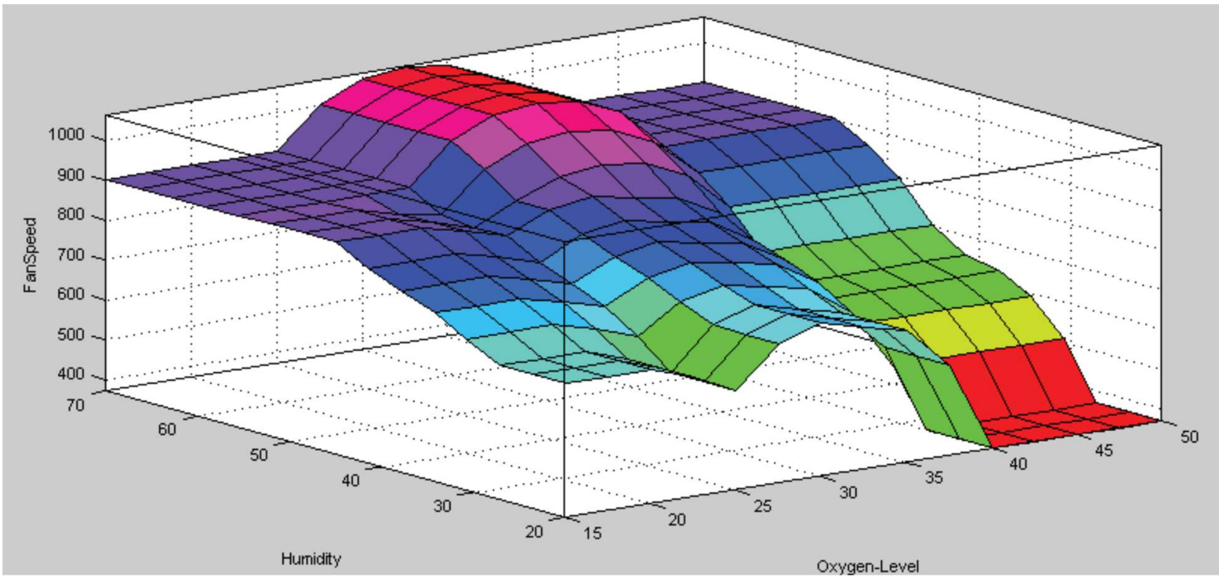

Figure 11. SV of fan speed with humidity and oxygen level.

Besides, Fig. 11 shows the impact of moistness what's more, oxygen level against the fan speed. As appeared in the figure when the oxygen level expands, the fan speed in diminishes because of the adequacy of oxygen in the room, which advances solid cool. On different hands, at the point when the dampness expands, the fan speed will increment to upsurge the oxygen level. In this manner, advancing the mugginess level is fundamental so as to accomplish an agreeable level for the client. What's more, as the mugginess builds more than 45% the controller will react to this change and move from AC mode to dehumidifier mode. The reason of dehumidifier mode is to improve the stickiness level in the space to a worthy stickiness level. Therefore, the AC mode will stay to cool up the room when the temperature is high and to keep up the client characterized target temperature. The surface watcher of balance heading versus oxygen level demonstrates that, when the oxygen level is as low as 15% to 35%, the blade bearing is toward to the client. This is to make sure the oxygen level is kept up at the adequate level for the client's solace and wellbeing. Then again, when the oxygen level is higher than 35%, the blade bearing will consequently move away from the client just to keep up the predefined room temperature. This infers, when the room is topped off with adequate clean air with enough oxygen, the balance course can be any side of the room. At long last, when the stickiness spans to a certain awkward level as characterized in the past rules, the fan speed will increment and the balance heading will be coordinated towards the client to invigorate the damp air.

5. Conclusions

This paper reported the realization, design, and application of the FL based controller systems and involved processes useful for class room. The developed FL controller could easily produce different output levels with efficiency. Using the proposed FL it was possible to scale and control the indoor air processing demand at the desired temperature and relative humidity level. The performance evaluation of the FL controller based air conditioners revealed its effectiveness in the classroom setting. To train the FL based control system simple Matlab program was developed and rule tables were created for decision making. Wide range of inputs and outputs were programmed with less complexity than traditional controllers. In short, the FL based controllers outperformed over the traditional ones in terms of the indoor temperature and relative humidity control. In future we will come up with a device that implements the Fuzzy Logic controller in an embedded system which can be used for increasing the efficiency of Air Conditioners.

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