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Fuzzy Based Temperature Control Analysis for Automotive Air Conditioning System

[1]I.Tijjani and [2]H. A. Bashir

[1]DFKI Bremen Universitat Bremen, Robotics Innovation Center.
[2]Electrical Engineering Department, Bayero University, Kano.
ibraheemtijjani4u@yahoo.com, habashir.ele@buk.edu.ng

Research Article

Abstract

Effective control of an Automotive Air Conditioning (AAC) system is complex since it deals with both heating and cooling as a result of the fixed or single temperature setting. The existence of steady-state error (SSE) is common in many climate controls models such as in the Stateflow switching controller in Matlab Simulink. This paper aims to develop an automatic temperature control scheme for the AAC system using the type I Fuzzy Logic Controller (FLC). It also analyzes the AAC system response by simulating the fuzzy control algorithm in Matlab Simulink; the FLC design goal is to minimize the undershoot in the PID based control of the climate control model while maintaining the desired temperature with real time response. To assess the performance of the proposed system, a simulation was set up to match a range of user-specified reference temperatures (15°C, 20°C and 25°C). The obtained simulation results revealed that in contrast to a PID controlled AAC system, the proposed FLC based system reduced the undershoot to only 2.33% from a 33.33% observed from the PID based system.

Keywords
Fuzzy logic control; Dynamic model; AAC system; Temperature control

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1. Introduction

Air conditioning (AC) is a process of regulating heat and moisture content in an enclosed space in order to enhance thermal comfort and ensure air quality. They are used in domestic (homes), commercial (offices, public buildings), and industrial (nuclear reactive system) environments.

Automotive Air Conditioning (AAC) by definition refers to a car’s integrated heating, ventilation, and air conditioning (HVAC) system (Homod, 2013). For automobiles, the HVAC system provides a comfortable climate in the cabin for the occupants by maintaining the temperature and humidity at a desired preset level. In general, the operation of AAC systems is subject to variabilities in thermal loads such as variations in the amount of sunlight incident on the windshield, side windows, door leakages, as well as several passengers on board.

As shown in Figure 1, an AC system generally comprised the following main parts: compressor, condenser, receiver/drier, expansion valve, and evaporator.

When the AC is switched on, the thermostat control sends an alternating current to the compressor motor. Upon receiving a voltage signal, the compressor absorbs low pressure (L.P.) refrigerant gas from the evaporator via the compressor coils and compresses it into a high pressure (H.P.) gas. The condenser receives a H.P. gas from the compressor and condenses the gas to a H.P. liquid. This is then channeled into the condenser coils for heat dissipation and then into the receiver dryer. The receiver dryer has an upper part as a filter dryer which serves as a compensation chamber that can only filter and remove small amount of moisture in the refrigerant. The lower part serves as refrigerant storage before the liquid is then passed through the expansion valve which in turn expands the H.P liquid into a L.P liquid.

The evaporator is located in the vehicle cabin space; the L.P liquid refrigerant from the expansion valve enters the evaporator through the evaporator coils. At this point, it expands the L.P liquid into L.P gas by absorbing heat thereby cooling the compressor coils. The gas flows to a suction line attached to the compressor, while the fan motor pulls air onto the evaporator coils before recirculation. The compressor receives the L.P gas from the evaporator and the cooling cycle continues.

For the vehicle climate control system, automatic control is essential. Fuzzy logic is widely used in automatic control. The concept of fuzzy logic, as conceived by Lofty Zadeh in 1965, became a tool for dealing with problems exhibiting uncertainties and imprecision in intelligent control of complex dynamical systems (Zadeh, 1965).

Fuzzy logic control (FLC) is a control system strategy conceptualized from fuzzy logic (Witold, 1993 and Hajek, 1998). Unlike classical logic which assigns a discrete value of either 0 or 1 to a physical control parameter, FLC allows the description of system parameters to belong to logic 0 or 1 to some degree.

As shown in Figure 2, FLC comprises a Fuzzifier, inference engine, set of rules, and a Defuzzifier. In a process called fuzzification, an input data in its original form (crisp) is converted into a fuzzy set using a set of linguistic variables and membership functions by the fuzzifier. Then, fuzzy output variables are generated following an inference made by the inference engine using the rule base. The final stage deploys the membership functions to transform the fuzzy output into a crisp one in a process known as defuzzification.

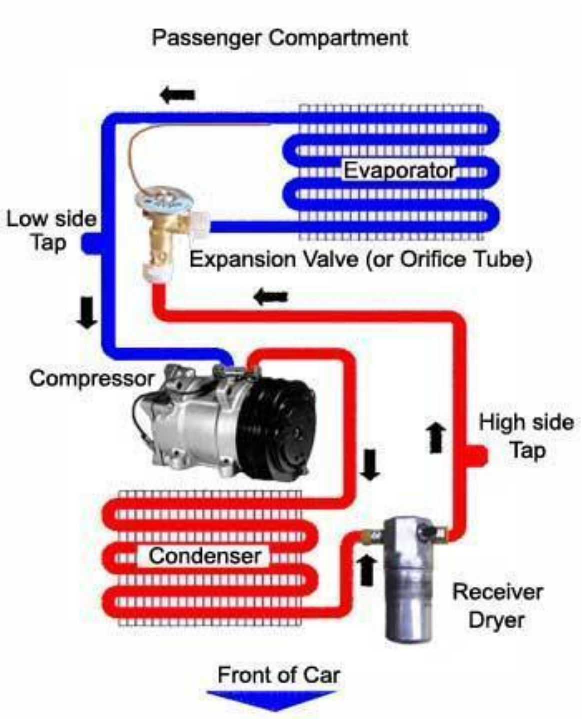


Figure 1: Schematic Diagram of a Basic AC System, (Thakrel, 2015)

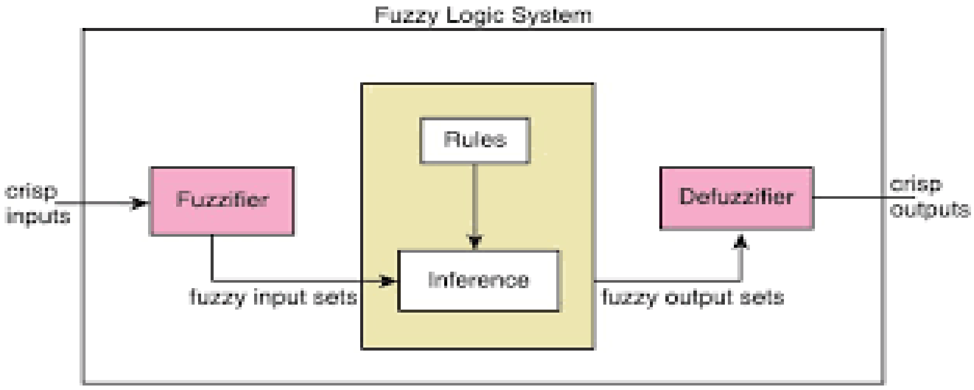


Figure 2: Fuzzy Logic System (Saravanakumar *et al.*, 2014)

2. Literature Review

Waheed *et al.* (2020) formulated a problem for tuning temperature and humidity level of air in a classroom setting using the fuzzy logic-based control. They provided a performance index which was used to compare with other traditional controllers. Their results revealed that the FLC performed better than traditional controllers in achieving a target temperature within a set time.

Behrooz *et al.* (2018) reviewed numerous control methodologies for HVAC systems concerning their nonlinear behavior. After the investigation of some classical control methods like the optimal control, model predictive control, adaptive control method, and PID control, they proposed the fuzzy cognitive mapping method to address the problems with nonlinearity, coupling effect, and other complexities of the HVAC systems. Their investigation revealed that a key challenge of the HVAC systems has to do with variation in system parameters.

Giulia *et al.* (2016) investigated and compared the energetic performance of three different control logics (on-off, PID, fuzzy), as used to regulate the emission of the heating system of an energy-efficient building. Simulation results showed that the FLC had better performance compared to the PID and the on/off controllers. It significantly improved energy efficiency but unable to attain desired setpoint temperatures.

Kumar (2013) investigated the control of static room AC with continuous monitoring of the thermal variables. The work monitors both the room temperature and humidity. The results of the household AC control performance for both FLC and PID controller showed that the FLC achieved its target temperature with a faster response than the PID controller.

Thakrel (2015) designed an FLC for automotive AC with temperature and humidity sensors deployed to provide feedback in the control system. The author’s investigation revealed the dynamical relationships in the refrigerant charge, evaporator air-side temperature, condenser water temperature, and the mass flow rate of circulation in the AAC system.

Betzaida and Miguel (1999) assessed a nonlinear controller for an HVAC system designed to maintain comfort under time-varying thermal loads. The results of the disturbance rejection state feedback controller were promising but suffered a long settling time with overshoot.

Takanori *et al.* (2011) presented a PID control scheme for a room AC system with reset functionality for thermal load regulation. The conventional PID tuning method was compared with a modified tuning method with an adjustable reset configuration. Despite the reset capability of the modified PID control, it was difficult for it to maintain the temperature at the desired setpoint without some fluctuations around the setpoint.

Hamed (1999) compared fuzzy logic and classical controller design for a nonlinear AC system with different temperature ranges for thermal comfort. Two FLC's were designed; the FLC blower controls the fan speed while the FLC switch controls the heating and cooling states. The two FLC's are not independent since they work in conjunction with one another. Thus, when one fails, the other system also fails. This affects the robustness of the overall system.

3. Materials and Method

This section presents the PID and Fuzzy based temperature control simulation in MATLAB Simulink. It is applied to an adopted dynamical model of the AAC system. For the analysis of the temperature scheme; the simulation is used to observe and compare the performances of both PID and FLC for the AAC system. In the following sub-sections, this paper describes the FLC design implementation, flow chart of the FLC temperature monitoring process, and the PID-Fuzzy control system design.

3.1 Dynamic Mathematical Model of the AAC System

The first-order differential equations describing the dynamical behavior of an AC system in Equations (1-3) were derived from energy conservation principles by (Betzaida and Miguel, 1999) as adopted in this work. There are three (3) state variables; T_3 represents the output temperature of the thermal space in ºC, T_2 is the input supply air temperature in ºC and W_3 represents the humidity ratio of the thermal space in kg/kg. The air volumetric flow rate F, in meter cube per second, is used as a second input variable when the system is implemented as a multi-input multi-output system, but since this system adopts a single input as the supply temperature, the air volumetric flow rate becomes a constant parameter. All the other constant parameters and their numerical values (Betzaida and Miguel, 1999 and Abduljabar, 2011) are presented in Table 1.

As a form of optimization with regards to the state of the art in AAC's, the former work of (Betzaida and Miguel, 1999) was later improved by (Abduljabar, 2011) of which the experimental performances were efficient enough to be incorporated in an automobile.

$$\frac{dT_3}{dt} = \frac{60F}{V_s}(T_2 - T_3) - \frac{60h_{fg}F}{C_pV_s}(W_s - W_3) + \frac{1}{(1-\mu)C_pV_s}(Q_0 - h_{fg}M_0) \tag{1}$$

$$\frac{dW_3}{dt} = \frac{60F}{V_s}(W_s - W_3) + \frac{M_0}{\rho V_s} \tag{2}$$

$$\frac{dT_2}{dt} = \frac{60F}{V_{he}}(T_3 - T_2) + 60F(1-\mu)\frac{(To - T_3)}{V_{he}} - 60F\frac{h_w}{C_pV_{he}}\left[(1-\mu)W_0 + \mu W_3 - W_s\right] - 6000\frac{gpm}{\rho C_pV_{he}} \tag{3}$$

Table 1: Numerical values for AAC system Parameters

S/No	Parameter name	Parameter Notation	Numerical Values
1	Specific heat of air	Cp	1.005KJ/kg
2	Moisture load in the conditioned space	Mo	0.021kg/s
3	Density of moist air	ρ	1.23kg/m^3
4	Sensible heat load in the conditioned space	Q_0	84.94KW
5	Chilled water flow rate	gpm	1gal/min
6	Volume of heat exchanger	V_{he}	0.004m^3
7	Enthalpy of water	h_w	4.2 KJ/kg
8	Latent heat of vaporization of water	h_{fg}	2450KJ/kg
9	Temperature of outdoor air	T_0	30°C
10	Specific volume of superheated refrigerant	V_s	0.093 ()
11	Humidity ratio of supply air	W_s	0.009()
12	Humidity ratio of outdoor air	W_0	0.018 ()
13	Supply air temperature	T_2	15°C
14	Air volumetric flow rate	F	1.7 ()

3.2 Fuzzy Logic Controller Design

Figure 3 shows the FLC design which consists of four (4) key segments. The linguistic variables comprising of input and output fuzzy variables, the triangular membership functions are used on the Mamdani inference mechanism, and the rule base determines the firing of the rules that produce the crisp output. The processes involved are fuzzification of the input linguistic variables (which include a change in temperature and rate of e temperature change, see Figure 4) by the fuzzy inference engine. Then, a set of control rules that demulsifies the output compressor speed to a crisp output in form of a control signal. Each of the input and output variables has five (5) separate membership functions (Figure 5) that define their functionality. Thus, a twenty-five (25) set of rules (Table 2) that determines the firing of the controls are developed to form a crisp output. The crisp output, after defuzzification process, corresponds to a voltage signal that is sent to the converter embedded in the vehicle. The actuation of the compressor motor by the car engine when the AC thermostat is put ON engages the DC-DC converter to draw in refrigerant gas and enhance cooling. The remaining processes from the crisp output to the thermal cooling of the AAC are performed by the vehicle system.

i. Linguistic Variable

This is a form of language module understood by the fuzzy controller which accepts input variables in a distinct form. Either with Mamdani or Sugeno approach, it defines inputs based on individual type of design.

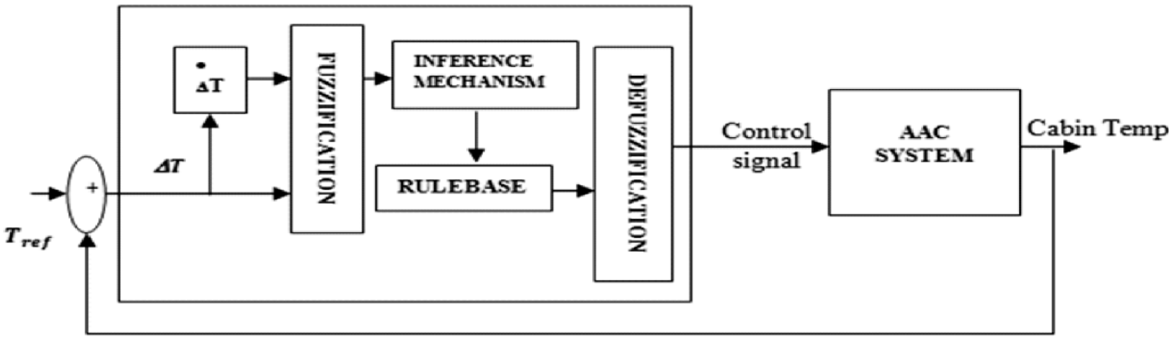


Figure 3: Block Diagram of the Proposed FLC Design for the AAC System

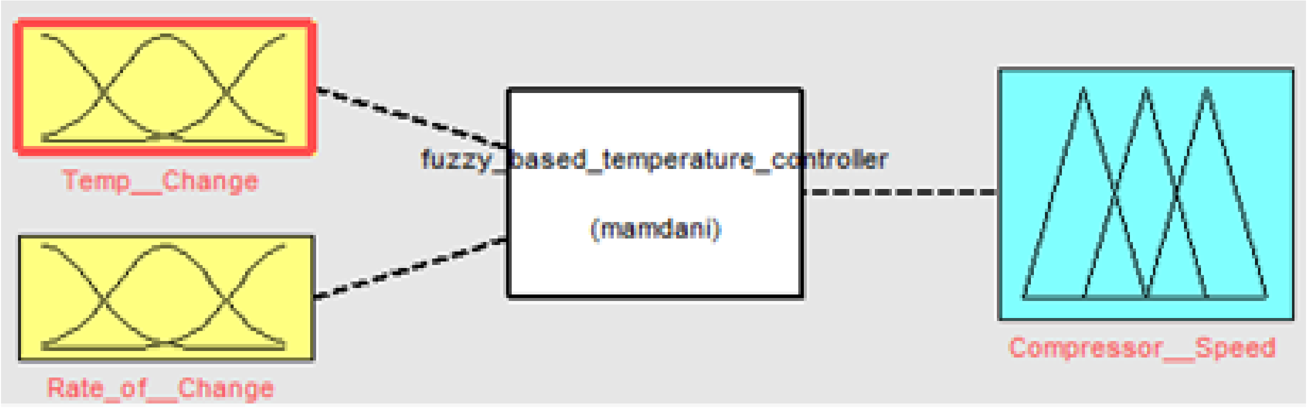
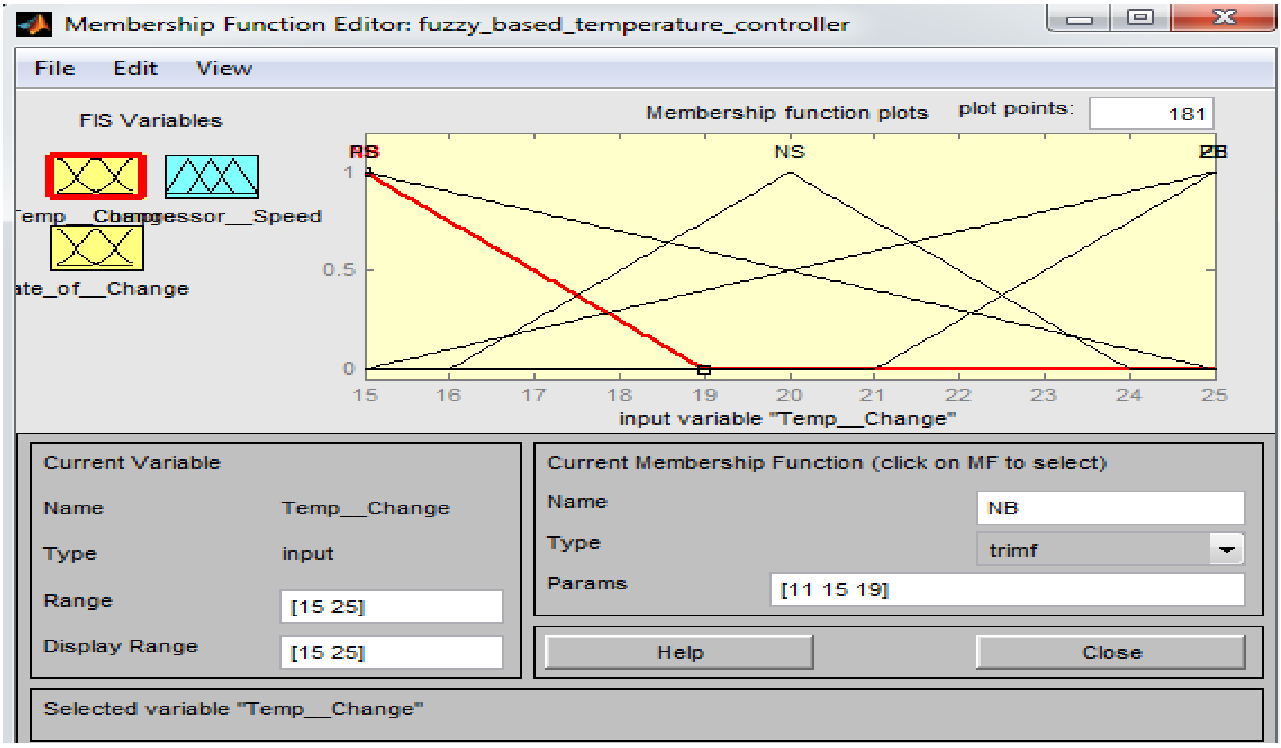


Figure 4: Linguistic Variables for the FLC inputs and output

ii. Membership Functions

These are special ways of graphically mapping out fuzzy input and output sets and hence representing them in a fuzzy system.



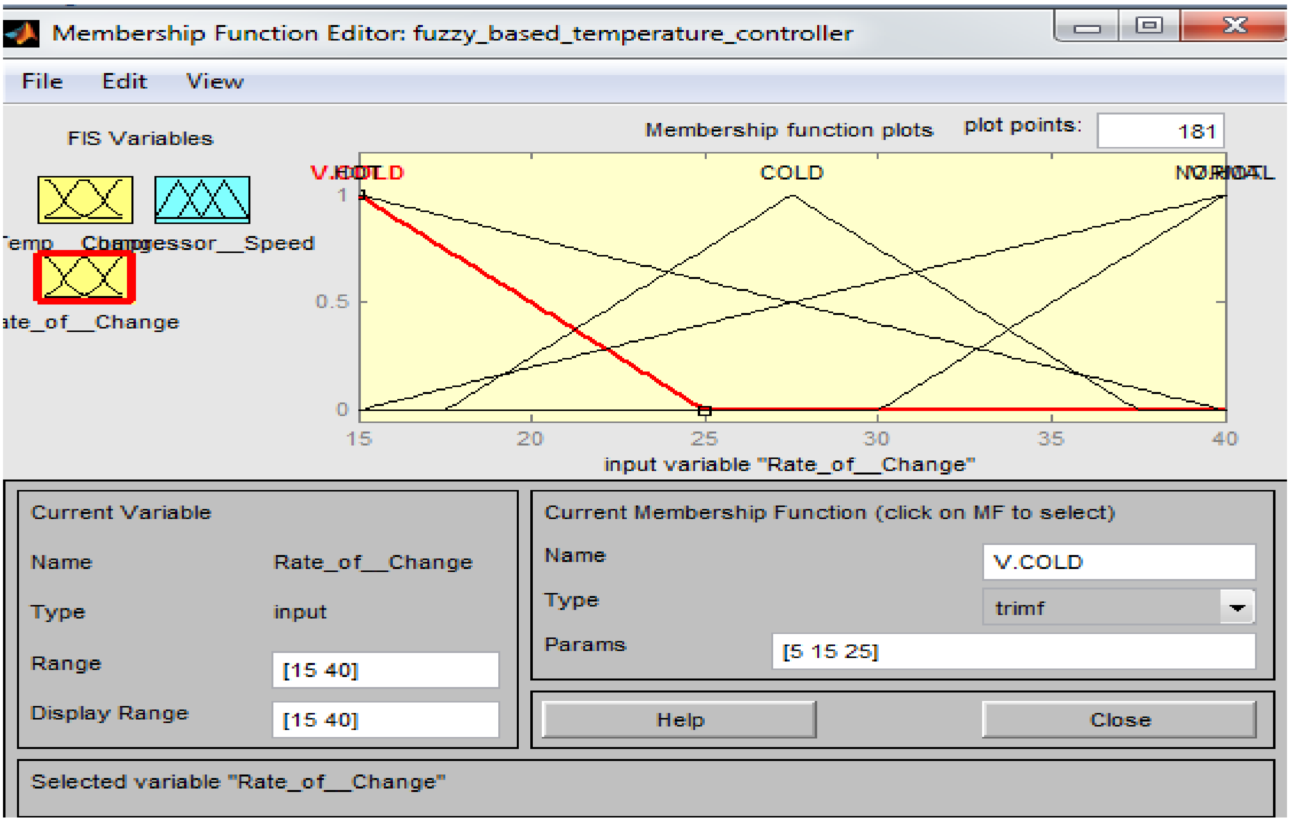
plot points: 181

Current Variable
Name: Temp__Change
Type: input
Range: [15 25]
Display Range: [15 25]

Current Membership Function (click on MF to select)
Name: NB
Type: trimf
Params: [11 15 19]

Selected variable "Temp__Change"

(a): Membership function for Input 1 mapping (temperature change)



Current Variable

Name Rate_of__Change

Type input

Range [15 40]

Display Range [15 40]

Current Membership Function (click on MF to select)

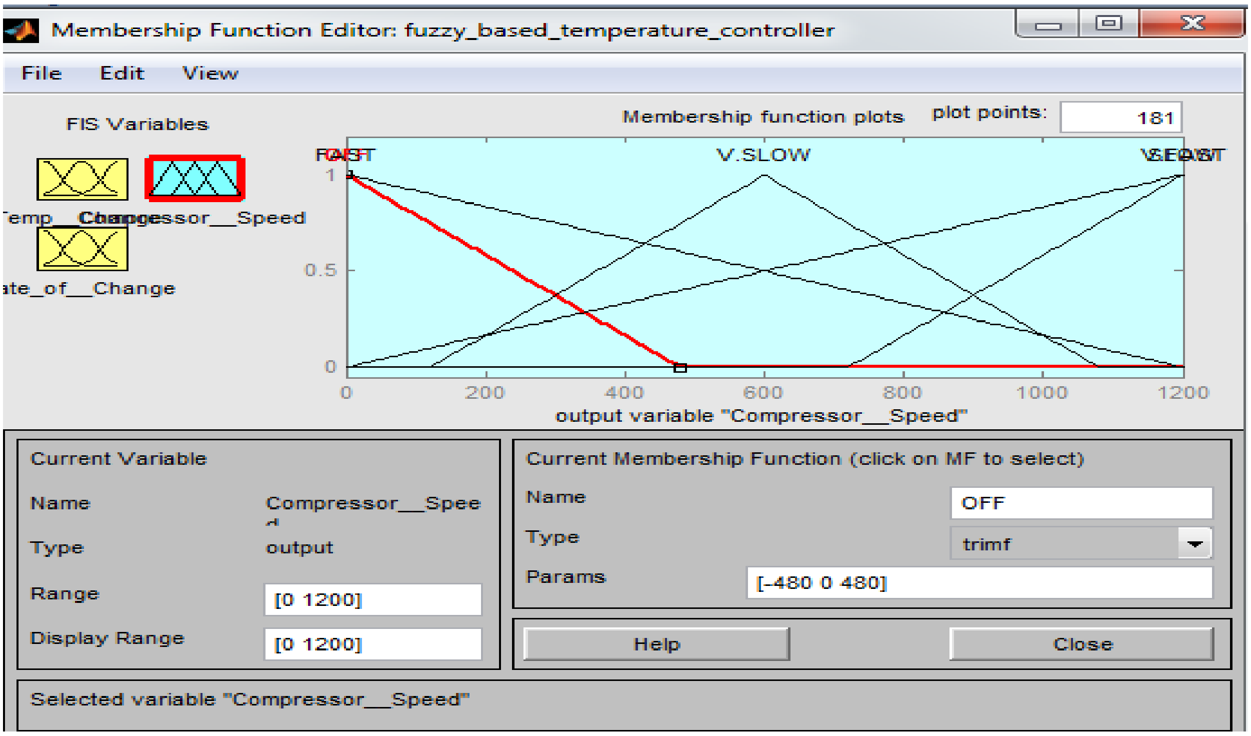
Name V.COLD

Type trimf

Params [5 15 25]

Selected variable "Rate_of__Change"

(b): Membership function for Input 2 mapping (rate of temperature change)



Current Variable

Name Compressor__Spee

Type output

Range [0 1200]

Display Range [0 1200]

Current Membership Function (click on MF to select)

Name OFF

Type trimf

Params [-480 0 480]

Selected variable "Compressor__Speed"

(c): Membership function for the Output mapping (Compressor speed)

Figure 5: Membership functions for the Input/Output Variables

iii. Fuzzy Rules

These are logical assignment to the fuzzy sets; they enhance different form of knowledge and reasoning which are later defuzzified into crisp outputs to be used by the system to be controlled.

Table 2: Rule base for the FLC-based AAC System

Fuzzy Rules

1.If (Temp Change is **NB**) and (Rate of Change is **V. Cold**) then (Compressor Speed is **LF**)
2. If (Temp Change is **NB**) and (Rate of Change is **Cold**) then (Compressor Speed is **LF**)
3. If (Temp Change is **NB**) and (Rate of Change is **Normal**) then (Compressor Speed is **FT**)
4. If (Temp Change is **NB**) and (Rate of Change is **Hot**) then (Compressor Speed is **FT**)
5. If (Temp Change is **NB**) and (Rate of Change is **V.Hot**) then (Compressor Speed is **FT**)
6. If (Temp Change is **NS**) and (Rate of Change is **V.Cold**) then (Compressor Speed is **LF**)
7. If (Temp Change is **NS**) and (Rate of Change is **Cold**) then (Compressor Speed is **LF**)
8. If (Temp Change is **NS**) and (Rate of Change is **Normal**) then (Compressor Speed is **LF**)
9. If (Temp Change is **NS**) and (Rate of Change is **Hot**) then (Compressor Speed is **LF**)
10. If (Temp Change is **NS**) and (Rate of Change is **V.Hot**) then (Compressor Speed is **LF**)
11. If (Temp Change is **ZE**) and (Rate of Change is **V.Cold**) then (Compressor Speed is **NM**)
12. If (Temp Change is **ZE**) and (Rate of Change is **Cold**) then (Compressor Speed is **NM**)
13. If (Temp Change is **ZE**) and (Rate of Change is **Normal**) then (Compressor Speed is **NM**)
14. If (Temp Change is **ZE**) and (Rate of Change is **Hot**) then (Compressor Speed is **NM**)
15. If (Temp Change is **ZE**) and (Rate of Change is **V.Hot**) then (Compressor Speed is **NM**)
16. If (Temp Change is **PS**) and (Rate of Change is **V.Cold**) then (Compressor Speed is **LS**)
17. If (Temp Change is **PS**) and (Rate of Change is **Cold**) then (Compressor Speed is **LS**)
18. If (Temp Change is **PS**) and (Rate of Change is **Normal**) then (Compressor Speed is **LF**)
19. If (Temp Change is **PS**) and (Rate of Change is **Hot**) then (Compressor Speed is **LS**)
20. If (Temp Change is **PS**) and (Rate of Change is **V.Hot**) then (Compressor Speed is **LS**)
21. If (Temp Change is **PB**) and (Rate of Change is **V.Cold**) then (Compressor Speed is **LS**)
22. If (Temp Change is **PB**) and (Rate of Change is **Cold**) then (Compressor Speed is **LS**)
23. If (Temp Change is **PB**) and (Rate of Change is **Normal**) then (Compressor Speed is **F**)
24. If (Temp Change is **PB**) and (Rate of Change is **Hot**) then (Compressor Speed is **VS**)
25. If (Temp Change is **PB**) and (Rate of Change is **V.Hot**) then (Compressor Speed is **VS**)

The acronyms for the Rule base are as follows:
Change in Temperature (NB=Negative Big, NS=Negative Small, ZE= Zero, PB= Positive Big, PS=Positive Small)
Rate of Change in Temperature (Very Cold, Cold, Very Hot, Hot and Normal)
Compressor Speed (FT=Fast, LF= Less Fast, LS=Less Slow, VS=Very Slow, and NM=Normal)

3.3 The Automatic Temperature Control Process

The temperature control process works in an automatic form, as soon as it is engaged by the user (Figure 6) with the start button. The user inputs a defined reference temperature (T_r) which is set to a specific range, the system then reads the cabin temperature (T_c). Then, based on whether or not the cabin temperature reaches the user-defined reference temperature, the FLC is invoked to control the AAC; thus, cooling the cabin space and maintaining the cabin temperature at the desired set point. When it attains the set point temperature, the system continues to monitor the cabin temperature paving way to an endless loop until the desired condition is ascertained.

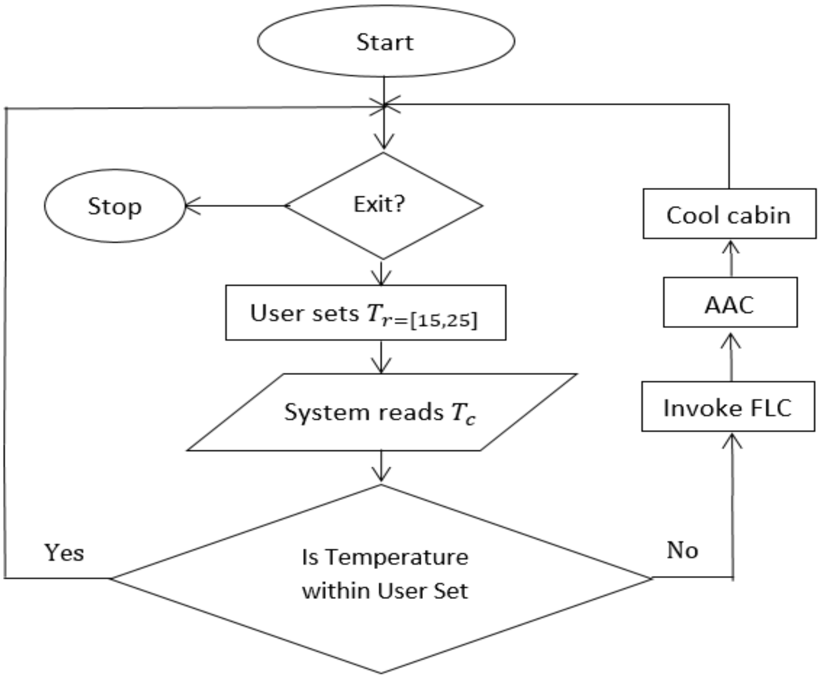


Figure 6: Flow Chart for the Temperature Control Process

3.4 Implementation and Simulation of the FLC Controlled Closed Loop AAC System

To evaluate the performance of the fuzzy logic controller and compare it with a classical PID controller, the proposed AAC system has a feedback that senses the current temperature in the cabin space and chooses the desired temperature based on the current input from the defuzzified rule base of the crisp output. Figure 7 shows the blocks (compressor, condenser, receiver/drier, expansion valve, and evaporator) which are embedded in the AAC compartment. When the thermocouple located in the cabin space is put ON, the FLC sends its output voltage signal to the automobile DC-DC converter which then induces the compressor and the internal AC operation is performed to allow thermal cooling in the cabin space. The compressor speed is dependent upon the voltage signal received from the fuzzification of the rule base which decides the level of conditioning the cabin space receives. The processes involving the converter to the evaporator embedded in the cabin space are internally operated by the AC system and have no analytical design with regards to the FLC simulation in this research work.

The proposed FLC system is implemented in MATLAB Simulink. Figure 8 depicts the simulation model of the FLC-based AAC controlled system. A setpoint temperature is applied to the comparator; the input to the FLC is a change in temperature and rate of e temperature change. The output of the FLC is a voltage signal sent to a converter that engages the compressor part of the AAC system. Hence, at the output, the measured temperature in the cabin space is sent as a feedback.

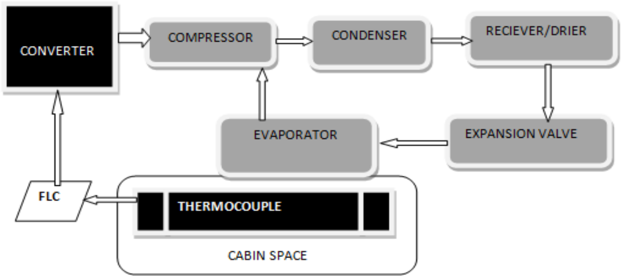


Figure 7: Block Diagram of a Closed loop AAC system with an FLC

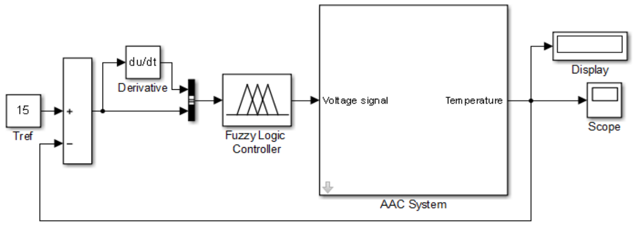


Figure 8: Simulink block model of the FLC based AAC system

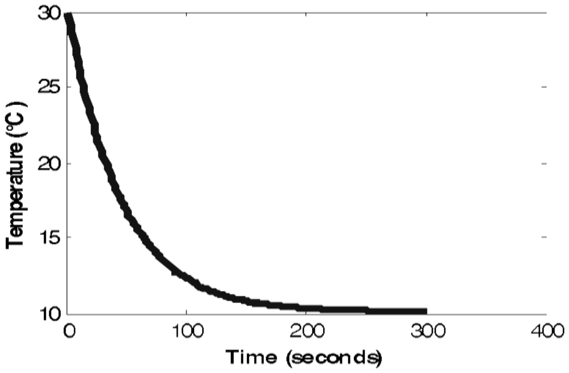
4. Results and Discussion

4.1 Experiment and Results

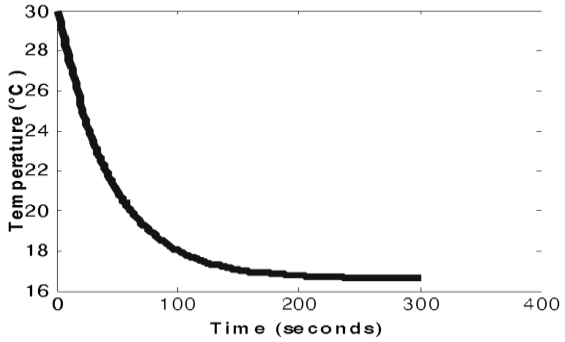
This section presents the graphical representation obtained from simulation for both the PID and FLC for the AAC system. It also, depicts the comparison between PID controller and FLC.

4.1.1 Response of the PID Controller Based AAC System

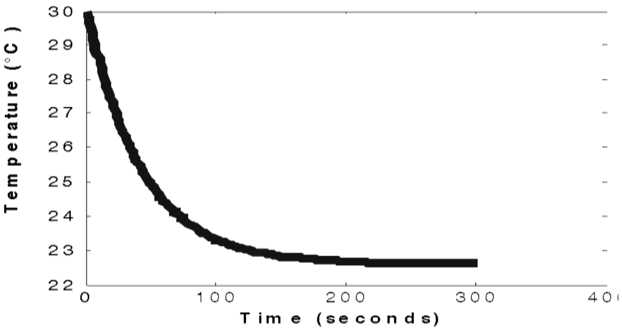
The three (3) graphical results in Figure 9 depict the response of the PID based AAC system for 15°C, 20°C and 25°C setpoint temperatures. The system was set to run for 5 minutes for each of the three set points, for an operating cabin temperature of 30°C. It could be observed that for everyone of the set point temperatures the response exhibits a steady state error, i.e., the system settles to a level below the desired set point. This is unwanted since the goal in this work is to ensure convergence to the desired set point.



a): 15°C Step Set Point

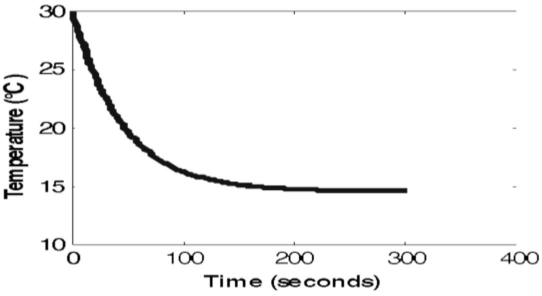


(b): 20°C Step Set Point

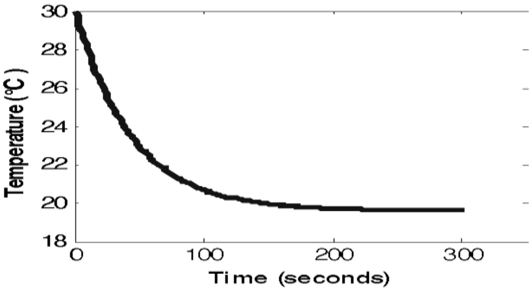


(c): 25°C Step Set Point

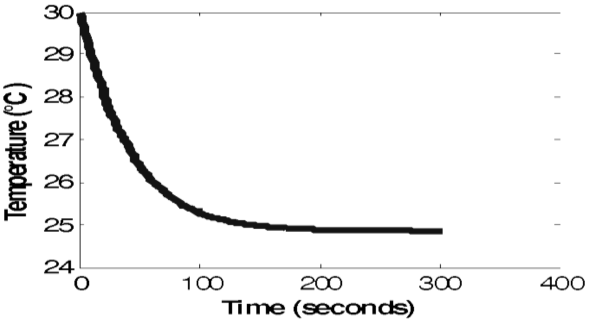
Figure 9: Cabin Temperature Set Point Response for PID based AAC System



(a): 15°C Step Set Point



(b): 20°C Step Set Point



(c): 25°C Step Set Point

Figure 10: Cabin Temperature Set Point Response For FLC based AAC System

4.1.2 Response of the FLC Based AAC System

In this simulation, the proposed FLC for the AAC system was evaluated for 15°C, 20°C and 25°C setpoint temperatures. The system was set to run for 5 minutes for each of the three set points, for an operating cabin temperature of 30°C. The results shown in Figure 10 revealed that the application of FLC was able to achieve the desired set point temperatures with little or no steady-state error and eliminates the undershoots.

4.1.3 Comparison between FLC and PID Controller based AAC System

The goal of applying the FLC to the AAC system is to minimize or eliminate undershoot inherent in the previously reported PID system (Takanori et al., 2011) while maintaining an acceptable speed of response. In this simulation, the PID controller response was compared with the FLC for the AAC system and evaluated for an average of 15°C setpoint temperature. The system was also set to run for 5 minutes starting with an operating cabin temperature of 30°C.

The same parameters are used for the FLC and the PID controller based AAC model in the Simulink design. However, the Ziegler and Nichols method was used to tune the PID parameters. Hence, the step response of the PID based AAC system was investigated with the proportional, integral and derivative gains of the PID respectively tuned to K_p=11.65, K_i=4.57 and K_d=1.16.

The graphical results shown in Figure 11 revealed that the PID based AAC system deviates from the setpoint temperature with a steady-state error of almost 〖5 〗^0 C. The FLC based system, however, attained the setpoint temperature, minimized the steady-state error and eliminates the undershoots.

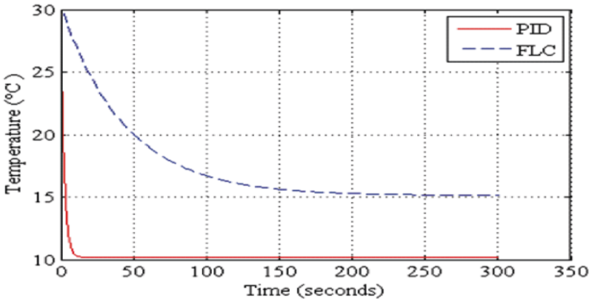


Figure 11: Comparison between FLC and PID Controller with 15°Cset point

Table 3 summarizes the detailed results comparing the performance of the PID controller system against the FLC-based AAC system.

4.2 Discussions

Automobiles are been manufactured every day with many constraints in thermal features. The quest to produce automobiles having more efficient AAC system that can better withstand the constraints across the temperate and tropical regions of the world, while improving thermal comfort, is still ongoing.

In this work, the Matlab Simulink have been used to simulate the temperature control system of an AAC in order to analyze the drawbacks in the existing system and proffer a more efficient way of improving AAC performance.

The numerical result, shown in Table 3, revealed the temperature of the cabin space with regards to the percentage steady-state error and settling time in both the PID and the FLC based AAC control systems for a set point temperature of 15°C. While a 33.33% error (corresponding to 5°C temperature error) is observed from the PID based system, only 2.33% error (corresponding to 0.35°C temperature error) is observed from the FLC based system. Additionally, while the settling time of the FLC based system is obviously longer than that of the PID system, the FLC based system achieves better thermal comfort by settling much closer to the set point temperature.

Table 3: Evaluation Results for Step Response Test on the AAC System

Controller	**Setpoint Temperature (°C)**	**Cabin Temperature (°C)**	**Settling Time (seconds)**	**Steady-State Error (%)**
FLC	15	14.65	250	2.33
PID	15	10	10	33.33

5. Conclusion

In this paper, an FLC based temperature control has been designed and simulated in Matlab Simulink for an AAC system. The analysis and controller designs were aimed at evaluating the PID controller performances and curtailing its limitations by application of an intelligent Fuzzy Logic control system. The proposed system used a single FLC to control the cabin temperature based on a user-specified range of temperature. Simulations were carried with both PID and FLC. Evaluation from the results obtained revealed a 33.33% steady state error and temperature undershoot in the PID based AAC system controller. On the other hand, the FLC based AAC system showed a significant reduction in the steady state error (2.33%) for various set point temperatures. Both controller schemes were also simulated together with a setpoint temperature of 15°C. Although, the settling time of the FLC based system is longer than that of the PID system, the FLC based system achieves better thermal comfort by settling much closer to the setpoint temperature.

References

Abduljabar, Z. A., (2011). Simulation and Design of Fuzzy Temperature Control for Heating and cooling Water System, International Journal of Advancements in Computing Technology, Vol 3.

Behrooz, F., Mariun, N., Marhaban, H., M., Radzi, M., A., and Ramli, A., (2018). Review of Control Techniques for HVAC Systems Nonlinearity Approaches Based on Fuzzy Cognitive Maps, Journal of Energies.

Betzaida, A., S., and Miguel, V., R., (1999). Nonlinear Control of a Heating, Ventilating, and Air Conditioning System with Thermal Load Estimation. IEEE TRANSACTIONS ON CONTROL SYSTEMS TECHNOLOGY, Vol. 7.

Giulia, U., Matteo, B., Alessandra, R., and Costanzo, P., (2016). Comparing the performance of on/off, PID and fuzzy controllers applied to the heating system of an energy-efficient building. Vol 116, pp. 1-17.

Hamed, B., (1999). Comparison between Fuzzy Logic and Classical Controller design for Nonlinear System. Thesis Mexico, New Mexico State University.

Hájek, P., (1998). Metamathematics of fuzzy logic (4 ed.). Springer Science & Business Media.

Homod, R. Z., (2013). Review on the HVAC System, Modeling Types and the Shortcomings of their Application, Journal of Energy, pp. 1-10.

Kumar, J., (2013). Comparative Analysis of Room Temperature Controller using Fuzzy Logic and PID. ISSN 2231-1297, Vol. 7

Othman, M. F., and Othman, S. M., (2006). Fuzzy Logic Control for Non Linear Car Air-conditioning, ELEKTRIKA,Vol. 8, no. 2, pp. 38- 45.

Pedrycz, W., (1993). Fuzzy control and fuzzy systems (2 ed.). Research Studies Press Ltd.

Saravanakumar, D., Mohan, B. and Muthuramalingam, T., (2014). Optimization of Proportional Fuzzy Controller for Servo Pneumatic Positioning System Using Taguchi: Data Development Analysis Based Ranking Methodology. Journal of Engineering & Technology, Vol. 4, no. 2, p. 115.

Singh, S. J. and Sharma, J. K., (2006). Fuzzy Modeling and Control of HVAC Systems: A Review, J. Sci. Ind. Res. pp: 470-476.

Takanori, Y., Yuji Y., Kazuyuki, K., and Shigeru, K., (2011). Air-Conditioning PID Control System with Adjustable Reset to Offset Thermal Loads Upsets. In Advances in PID Control, Ed. Yurkevich, V. D. IntecOpen, ISBN: 978-953-51-6043-4.

Thakrel, R. N., (2015). FLC for AAC: A Review, International Journal of Engineering Research-online (http://www.ijoer.in), ISSN: 2321-7758, Vol.3.

Waheed, R., S., Adnan, M., M., Suaib, M., N., Rahim, M., S., (2020). Fuzzy Logic Controller for Classroom Air Conditioner, International Laser Technology and Optics Symposium.

Zadeh, L. A., (1965). Fuzzy Sets, Information Control, Vol. 8. pp. 338-353.