TECHNICAL UNIVERSITY OF CLUJ-NAPOCA

ACTA TECHNICA NAPOCENSIS

Series: Applied Mathematics, Mechanics, and Engineering
Vol. 66, Issue I, March, 2023

OPTIMAL AND INTELLIGENT CONTROL OF CAR AIR CONDITIONING SYSTEM USING TYPE-2 FUZZY CONTROLLER

Pouya DERAKHSHAN BARJOEI, Zeinab JAVAHERI

Abstract: *Intelligent and efficient electronic and control systems have been designed and implemented on various vehicle to provide security and comfort for passengers. Considering that the temperature of the car cabin is considered one of the effective factors in the comfort of the car passengers. Therefore, with its control of the air conditioning system, in addition to creating comfort and increasing the travel safety factor, energy consumption can also be reduced. The control of the ventilation system is often done manually, which is not pleasant, and also with the development of technology, it is a customer-friendly option for a smart vehicle. Therefore, many methods have been provided for the intelligent control of the air conditioning system of the car.In this paper, due to the nonlinearity car air conditioning system, the theory of fuzzy systems of the type-2 fuzzy type was proposed and the cabin temperature regulation system was improved by simultaneously using the particle swarm optimization algorithm. The method of doing the work is that the performance of type-1 and type-2 fuzzy controller was investigated in different scenarios and in all cases it was found, that the type-2 fuzzy control system designed with the help of particle algorithm optimization is far It works better than fuzzy type-1.*

Key words: Car air conditioning system, fuzzy control type-2, Particle swarm optimization, Nonlinear Parameters.

1. INTRODUCTION

Nowadays, the use of intelligent methods along with the use of innovations obtained in the field of electronic and control systems, especially in the field of car air conditioning system, is very widely used.

In general, air conditioning is a system that can control temperature, humidity and air flow speed, or in simpler terms, by performing operations on the air, the air conditions of the desired place for living, working or certain industrial operations, comfortable and Sanitized and brought it to the desired level. The control of the air conditioning system makes the air conditions automatically remain constant or change according to a certain method [1]. With the proper control of this system, in addition to providing comfort, the safety factor of the trip can be increased and energy consumption can be reduced. Controlling the ventilation system was often done manually in the old days. In a research conducted in 2003 on the efficiency of driving in different weather conditions, it was concluded that the use of manual air conditioning control interferes with driving and as a result reduces the driving safety factor, therefore the automatic control of the air conditioning system is completely It is necessary and increases the efficiency and optimization of the system [2].

The temperature of the car cabin is one of the important factors in accidents. Temperature is known as the third most effective factor in accidents. There are many methods for intelligent control of car air conditioning system. Modern control theory and the use of statistical methods to determine the system model [4], microprocessor control system for continuous control of the cabin temperature by turning the compressor on and off [5], thermal comfort of the cabin using the optimized fuzzy controller method [3], Increasing the efficiency of the system and its energy management by using predictive methods and using information from systems such as GPS and GIS [6], intelligent adaptive control to control the ventilation

Received: 30.01.23; **Similarities**: 09.02.23: **Reviewed**: 23.02./07.03.23: A**ccepted**:22.03.23.

temperature [7], using machine learning algorithms along with the use of the decision-making process Markov has been used to adjust the cabin air control system [8], and predictive control with the aim of improving temperature control and minimizing energy consumption in the car air conditioning system [9].

The purpose of this research is to provide an intelligent fuzzy control method to regulate the cabin temperature in the air conditioning system of the car by simultaneously using the particle swarm optimization algorithm.

2. DYNAMIC MODEL OF CAR AIR CONDITIONING SYSTEM

A simple schematic of an air conditioning system is shown in Figure 1. The main components of the system include a variable speed compressor motor, an electronic expansion valve, an evaporator, and a condenser.

The compressor, as the heart of the system, is responsible for compressing and circulating the hot refrigerant vapor in a closed circulation system. The purpose of the condenser is to remove the heat stored in the refrigerant gas when it is compressed and evaporated, in fact, it turns the refrigerant gas into a liquid [1]. The expansion valve performs a sudden lowering of the pressure, as a result of which the temperature of the refrigerant also decreases, and the evaporator also turns the liquid refrigerant into gas. The differential equations of the dynamic behavior of the system using the expansion of the equations using the laws of conservation of mass and energy and the laws of thermodynamics are as follows [10-15]:

$$C_p \rho V \frac{dT_2}{dt} = C_p \rho f (T_1 - T_2) + k_{spl} f + Q_{load} \tag{1}$$

$$\rho V \frac{dw_2}{dt} = \rho f (w_1 - w_2) + \mathrm{M} \tag{2}$$

$$C_p \rho V_{h1} \frac{dT_3}{dt} = C_p \rho f (T_2 - T_3) + \alpha_1 A_1 \left(T_w - \frac{T_2 + T_3}{2} \right) \tag{3}$$

$$C_p \rho V_{h2} \frac{dT_1}{dt} + \rho V_{h2} h_{fg} \frac{dw_1}{dt} = C_p \rho f (T_3 - T_1) + \rho f h_{fg} (W_2 - W_1) + \alpha_2 A_2 \left(T_w - \frac{T_3 + T_1}{2} \right) \tag{4}$$

$$\left(C_p \rho V \right)_w \frac{dT_w}{dt} = \alpha_1 A_1 \left(\frac{T_2 + T_3}{2} - T_w \right) + \alpha_2 A_2 \left(\frac{T_3 + T_1}{2} - T_w \right) - s \frac{v_s}{\lambda V_{com}} (h_{r2} - h_{r1}) \tag{5}$$

$$\frac{dw_1}{dt} - \left(\frac{(2 * 0.0198 T_s) + 0.085}{1000} \right) \frac{dT_1}{dt} = 0 \tag{6}$$

The dynamic variables of the system are introduced in Table 1.

Table 1- Dynamic variables of system [10]

Parameters	symbol
Output Evaporator temperature	T_1
Evaporator outlet humidity	w_1
cabin temperature	T_2
cabin humidity	w_1
temperature of drying area	T_3
Evaporator wall temperature	T_w
Flow rate of passing air caused by the fan	f
Compressor speed	s

2.1. EXPLANATION OF DIFFERENT SCENARIOS

In the following, to evaluate the quality of the two designed controllers, we simulated and implemented the following scenarios:

1- Existence of a high temperature condition in the cabin before adjusting the fuzzy parameters

2- Existence of a high temperature condition in the cabin after adjustment of fuzzy parameters

3. HIGH TEMPERATURE CONDITION IN THE CABIN BEFORE ADJUSTING THE FUZZY PARAMETERS

In this case, we assume that initially the temperature of the cabin is 34 degrees. Now, using the first and second type of Fuzzy controller, we try to control the temperature value in the optimal setting of 22 degrees.

In Figure 1, it is clear that both controllers succeed in setting the temperature close to the desired temperature. As can be seen, two systems reach the desired temperature with the same time interval, but the amount of phase deviation of the first type from the desired temperature is more than that of the second type.

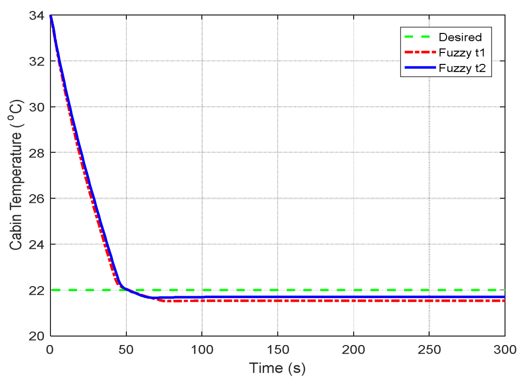

Fig. 1. System control in the presence of relatively high initial conditions in the cabin temperature before adjusting the fuzzy parameters

Next, from 130 to 170 seconds, we add a step disturbance to the system in the form of an increase in thermal load, which, as can be seen in Figure 2, the system has managed well. In this second type of fuzzy control, the temperature of the system is out of the stable state by a maximum of 0.65 degrees, but the first type of fuzzy control is out of the stable state by 0.95 degrees, which shows that in the first type of fuzzy system, disturbances have a stronger impact on the system.

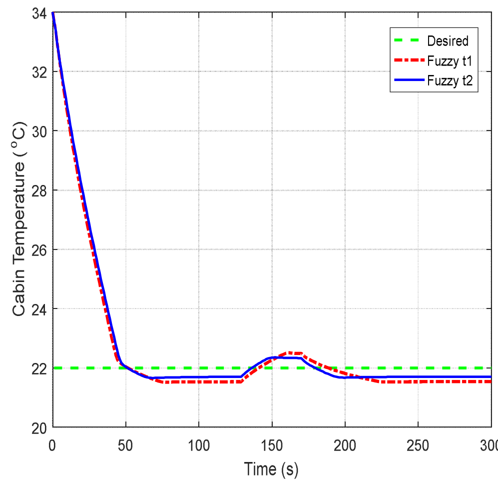

Fig. 2. System control, relatively high initial conditions in the cabin temperature before adjusting the fuzzy parameters in the presence of disturbance

4. HIGH TEMPERATURE CONDITION IN THE CABIN AFTER ADJUSTING THE FUZZY PARAMETERS

In this case, assuming the temperature of the cabin in the initial conditions is 34 degrees, using the first and second type fuzzy controller, after setting the fuzzy parameters, we try to control the temperature value in the optimal set conditions of 22 degrees. As can be seen in Figure 3, compared to Figure 1, after optimization, the persistent error of the system has been greatly reduced and the speed of the two systems to reach the desired temperature has improved by almost 50%. Also, fuzzy type two has been able to perform much better than fuzzy type one, and therefore both controllers have performed much better after optimization.

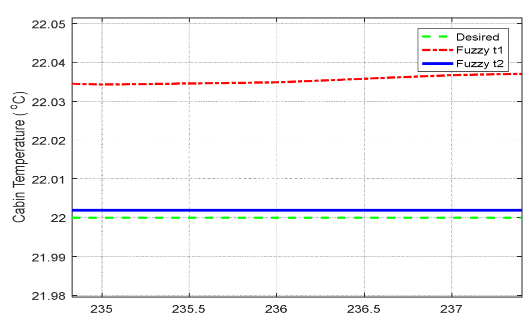

Fig. 3. System control, relatively high initial conditions in the cabin temperature after adjusting the fuzzy parameters

In the following, for a more detailed investigation of the disturbance, from the 100th to the 200th second, we add a random disturbance with a coefficient of 0.9 to 1.1 as an increase in thermal load to the system, which as can be seen in Figure 4, in the first type of phase, the disturbances cause The system is more strongly influenced and the second type of phase has a better reaction in the face of disturbances.

Table 2- Fuzzy rules database

error										
positive			Zero			negative				
positive	zero	negative	positive	zero	negative	positive	zero	negative	Error integration	
P3	P2	P1	P2	P1	Z	P1	Z	Z	negative	Error derivation
P4	P3	P2	P3	P2	P1	P2	P1	Z	zero	
P4	P4	P3	P4	P3	P2	P3	P2	P1	positive	

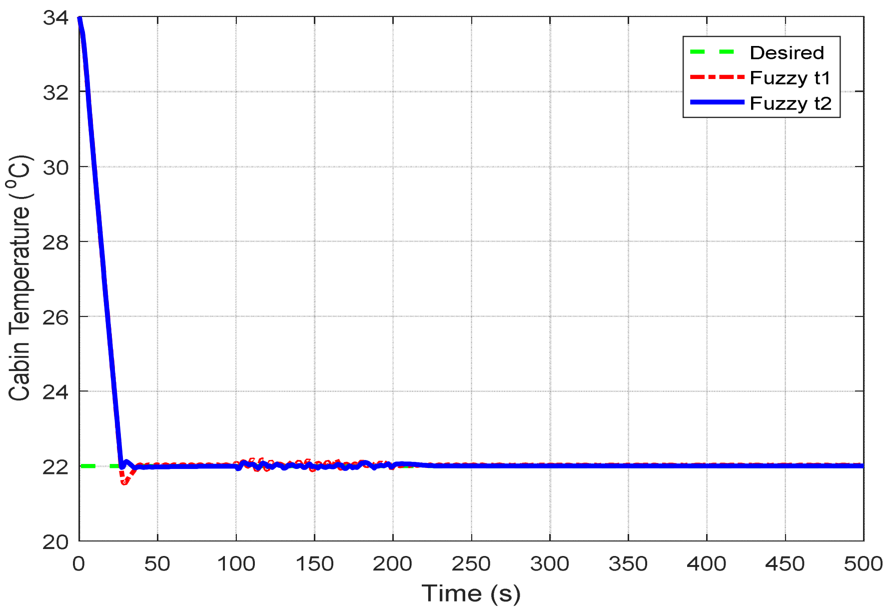

Fig. 4. System control, relatively high initial conditions in the cabin temperature after adjusting the fuzzy parameters in the presence of disturbance

5. ENERGY CONSUMPTION EVALUATION

In order to check the energy consumption, the output of type 2 fuzzy control is normalized before and after adjusting the type 2 fuzzy parameters, which can be seen in Figure 5. As can be seen, after reaching the desired temperature, energy consumption is lower in the optimized phase.

$$v_{id} = wv_{id} + c_1.rand.(p_{id} - x_{id}) + c_2.rand.(p_{gd} - x_{id}) \quad (7)$$

6. SIMULATION

In this section, we describe the design of a fuzzy system to regulate the cabin temperature based on changing the speed of the compressor. In this case, the speed of the compressor has been considered as the output of the control system and the input of the temperature regulation system. For this case, we considered the error as the difference between the desired temperature and the current temperature of the cabin at any moment. Then we considered the error as well as its integral and derivative as the input of the fuzzy system and the output speed of the compressor as the output of the Fuzzy system.

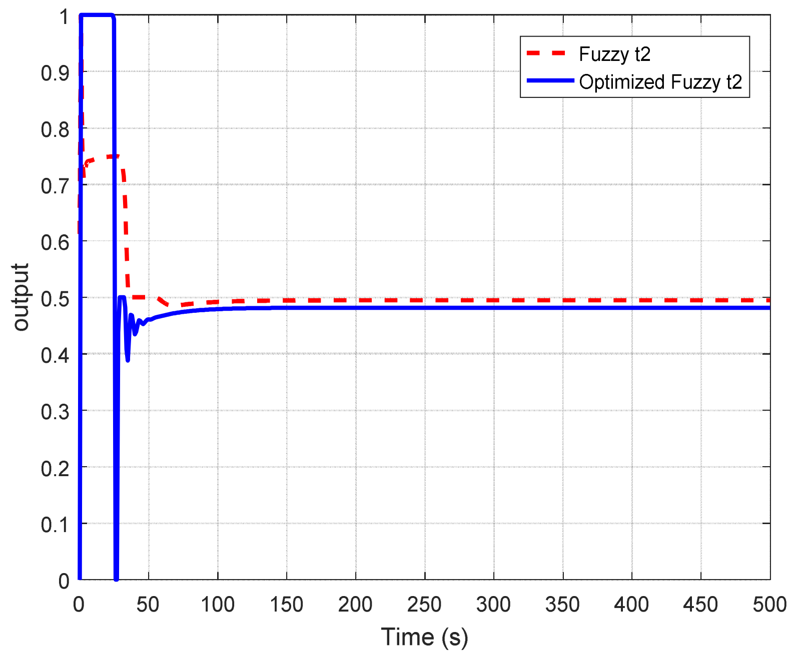

Fig. 5. Comparison of energy consumption in the type-2 fuzzy system before and after adjusting the fuzzy parameters

For each of the inputs of the fuzzy system three membership functions (Linguistic variables) named negative, zero and positive are considered as Gaussian function type. For the output variable, 5 membership functions named very low (Z), low (P1), medium (P2), high (P3) and very high (P4) of Gaussian function type are considered. The fuzzy rules are shown in Table 2. The type of fuzzy controller used is Mamdani. The method of obtaining output in Mamdani fuzzy system is seen in Table 3.

Table 3- Method of getting output in Mamdani fuzzy system

defuzzify	community	inference	OR	AND
Centroid	max	min	max	min

In setting the parameters, the help of particle cumulative algorithm was used, the beginning of PSO is that a group of solutions is randomly generated and by updating the generations, they try to find the optimal solution. In each step, each particle is updated using its current location and two best values. The first one is the best position that the particle has achieved so far. The mentioned position is known and maintained as pbest. The other best value used by the algorithm is the best position ever obtained by the particle population. This situation is shown by gbest.

All particles know their best location, the best location of group particles and also the value of the objective function corresponding to each location. In each step of the algorithm, the behavior of the particle is chosen as a random combination of these three possibilities:

1- Following the path of the particle itself
2- Returning to his previous best place
3- Going to the best previous or current location of the particles of the group

The behavior of the particle in this algorithm is formulated as follows[12]:

$$X_{i,t+1} = X_{i,t} + V_{i,t}$$

$$w(t) = \frac{(t_{\max} - t).(w_{start} - w_{end})}{t_{\max}} + w_{end} \qquad (8)$$

(9)

$X_{i,t}$: The location of the ith particle in iteration step t

Vi,t: the rate of change of location of the ith particle in the iteration step t

Pi,d: the best previous location of the ith particle in the iteration step t

Pg,d: the best location among all particles in iteration step t

C_1 ، C_2 , : constant coefficient

$r_{1,t}$, $r_{2,t}$: random value between (0,1)

In order to evaluate the performance of the controller, it is assumed that the initial temperature of the cabin is equal to 34 degrees and the ideal temperature is 24 degrees. It is set as desired.

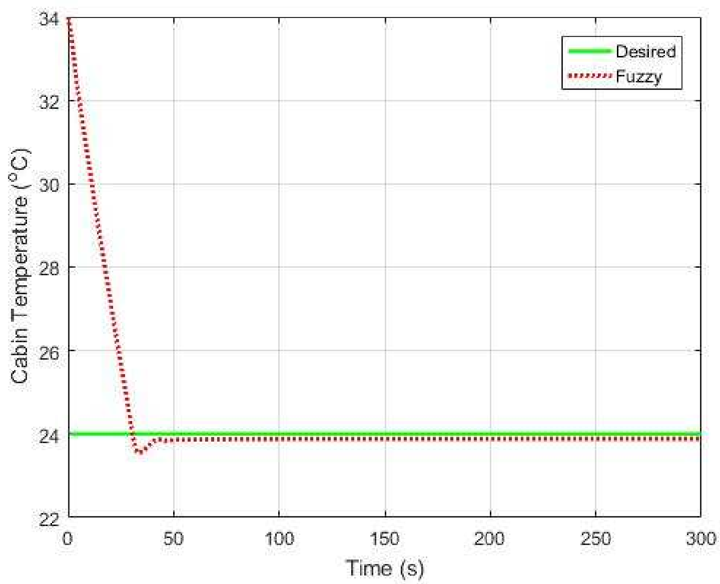

Fig. 4. System control in the presence of initial temperature conditions of 34 degrees

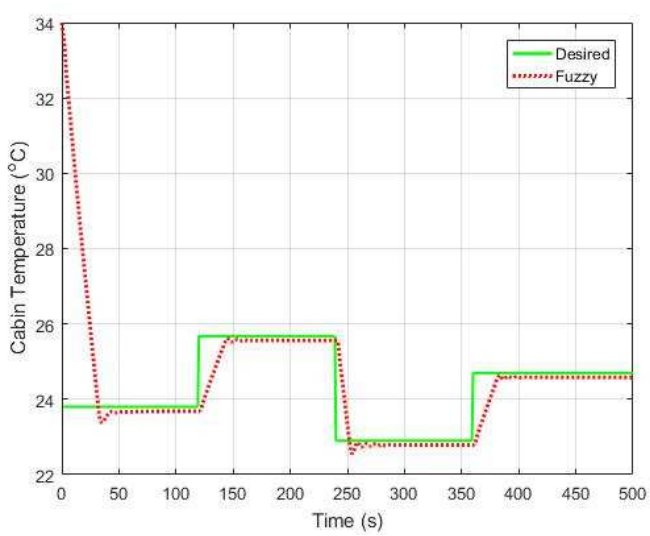

Fig. 5. Response of the controlled system in reference signal tracking mode

Next, we change the desired position of the cabin temperature and measure the efficiency of the control system by tracking the reference signal. As seen in Figure 5, after a few seconds, we changed the desired temperature several times and the designed fuzzy system was able to track the reference signal well.

7. . CONCLUSION

A fuzzy control method based on the particle swarm optimization algorithm designed and optimized. In addition, improvement in the performance of the temperature regulation system in the cabin of air conditioning system was presented. In this method, by using the dynamic model of the air conditioning system, according to the current measurements of the error, error integral and error derivative, the speed of the compressor is changed in such a way that the temperature is set at the desired level.

The performance of the designed fuzzy type -1 and type -2 controller was investigated in different scenarios and in all cases, it was found that the type -2 fuzzy control system performs much better than the type -1 fuzzy control, especially during disturbance presentation. After adjusting the fuzzy parameters with the PSO algorithm, the speed and accuracy have been improved. Also, energy consumption has been decreased after reaching a stable temperature in the optimized phase.

As seen, using this designation, the temperature of the cabin was adjusted in a favorable condition after a short time, and it also tracked the desired reference signal well.

8. REFERENCING

[1] Daly, S., (2011). Automotive air conditioning and climate control systems. Elsevier

[2] Daanen, H.A., Van De Vliert, E. and Huang, X., (2003). Driving performance in cold, warm, and thermoneutral environments. Applied ergonomics, 34(6), pp.597-602.

[3] Farzaneh, Y. and Tootoonchi, A.A., (2008). Controlling automobile thermal comfort using optimized fuzzy controller. Applied Thermal Engineering, 28(14), pp.1906-1917

[4] Tabe, T., Matsui, K., Kakehi, T. and Ohba, M., (1986). Automotive climate control. IEEE control systems magazine, 6(5), pp.20-24.

[5] Mohammad Javad Fattahi Hasan Abad and Pouya Derakhshan-Barjoei, . Heuristic Model of Cellular Learning Automata for Fuzzy Rule Extraction. Research Journal of Applied Sciences, Engineering and Technology, (12): 1701-1707.

[6] Ooi, T.H., Lau, K.T. and Lim, C.H., (1990). Controller for vehicle air-conditioning system. IEEE transactions on consumer electronics, 36(2), pp.66-75.

[7] Khayyam, H., Nahavandi, S., Hu, E., Kouzani, A., Chonka, A., Abawajy, J., Marano, V. and Davis, S., (2011). Intelligent energy management control of vehicle air conditioning via look-ahead system. Applied thermal engineering, 31(16), pp.3147-3160.environments. Applied ergonomics, 34(6), pp.597-602.

[8] Khayyam, H., (2013). Adaptive intelligent control of vehicle air conditioning system. Applied thermal engineering, 51(1), pp.1154-1161.

[9] Rosenfeld, A., Azaria, A., Kraus, S., Goldman, C.V. and Tsimhoni, O., (2015), May. Adaptive advice in automobile climate control systems. In Proceedings of the 2015 International Conference on Autonomous Agents and Multiagent Systems (pp. 543-551). International Foundation for Autonomous Agents and Multiagent Systems.

[10] Huang, Y., Khajepour, A., Bagheri, F. and Bahrami, M., (2016). Optimal energy-efficient predictive controllers in automotive air-conditioning/refrigeration systems. Applied Energy, 184, pp.605-618.

[11] Qi, Q. and Deng, S., (2008). Multivariable control-oriented modeling of a direct expansion (DX) air conditioning (A/C) system. International Journal of refrigeration, 31(5), pp.841-849.

[12] Kennedy, J. and Eberhart, R. (1995) Particle Swarm Optimization. Proceedings of the IEEE International Conference on Neural Networks, 4, 1942-1948.

[13] . Li-Xin Wang. 1996. A course in fuzzy systems and control. Prentice-Hall, Inc., USA.

[14] Subramaniyan, Arul Selvan and Pandian, Seethalakshmi, "A State Space Approach for the Dynamic Analysis of Automotive Air Conditioning System" (2010). International Refrigeration and Air Conditioning Conference. Paper 1079.

[15] P. Saengthong, C. Charnsripinyo, S. Laitrakun, Y. Hara-Azumi and S. Deepaisarn,(*2022).* "Thermal-comfort Control using Occupancy Detection and Fuzzy Logic for Air-conditioning Systems," *Joint (ECTI DAMT & NCON)*, 2022, pp.

CONTROL OPTIM ȘI INTELIGENT AL SISTEMULUI DE AER CONDIȚIONAT AUTO FOLOSIND CONTROLLER FUZZY DE TIP-2

Rezumat: Sistemele electronice și de control inteligente și eficiente au fost proiectate și implementate pe diverse vehicule pentru a oferi securitate și confort pasagerilor. Având în vedere că temperatura din cabina mașinii este considerată unul dintre factorii eficienți în confortul pasagerilor mașinii. Prin urmare, prin controlul său asupra sistemului de aer condiționat, pe lângă crearea de confort și creșterea factorului de siguranță în călătorie, se poate reduce și consumul de energie. Controlul sistemului de ventilație se face adesea manual, ceea ce nu este plăcut și, de asemenea, odată cu dezvoltarea tehnologiei, este o opțiune prietenoasă cu clienții pentru un vehicul inteligent. Prin urmare, au fost furnizate multe metode pentru controlul inteligent al sistemului de aer condiționat al mașinii.

În această lucrare, datorită sistemului neliniar de climatizare a mașinii, a fost propusă teoria sistemelor fuzzy de tipul fuzzy de tip 2 și a fost îmbunătățit sistemul de reglare a temperaturii cabinei prin utilizarea simultană a algoritmului de optimizare a roiului de particule. Metoda de realizare a lucrării este că performanța controlerului fuzzy de tip 1 și tip 2 a fost investigată în diferite scenarii și în toate cazurile s-a constatat că sistemul de control fuzzy de tip 2 proiectat cu ajutorul optimizării algoritmului de particule este departe Funcționează mai bine decât tipul fuzzy-1.

Pouya DERAKHSHAN BARJOEI, Dr., Assoc. Prof., Department of Electrical Engineering, Naein Branch, Islamic Azad University, Naein, Iran, dr.derakhshan@iau.ac.ir

Zeinab JAVAHERI, Department of Mechatronics Engineering, Science and Research Branch, Islamic Azad University, Tehran, Iran