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Control Strategy of New Energy Vehicle Interior Thermal Management System Based on Intelligent Assisted Algorithms

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Abstract. Reasonable and efficient utilization of pure electric vehicle thermal management system can improve the battery utilization rate of new energy vehicles, thereby increasing the vehicle's range and charging anxiety. This article proposes a new tram thermal management system scheme for temperature management in new energy vehicles, and designs corresponding thermal management system control strategies based on fuzzy adaptive PID control method. Finally, in order to verify the effectiveness of the management plan and control strategy, Matlab software was used for simulation. The simulation results showed that the intelligent control method proposed in this paper can increase the battery utilization rate by 17%..

Keywords: new energy vehicles, thermal management, fuzzy control, PID

1 Introduction

New energy vehicles are occupying the automotive market with strong momentum due to their lower usage costs and clean energy consumption. At present, the new energy vehicles on the market are mainly divided into three types: pure electric vehicles, plug-in hybrid vehicles, and extended range hybrid vehicles. According to statistics from relevant departments, since 2018, the sales of new energy vehicles in China have gradually increased to over 2 million units. With the significant increase in sales of new energy vehicles, it has also brought about electricity anxiety for a large number of car owners. In the auxiliary systems of automobiles, the energy consumption of the air conditioning system is an important factor affecting the energy consumption of the entire vehicle, especially in extreme weather conditions such as cold and hot weather.

Improving the performance and efficiency of the air conditioning system of new energy vehicles is of great significance for new energy vehicles. The main research object of this article is pure electric vehicles. Due to the fact that pure electric vehicles do not install internal combustion engines, there is no problem of utilizing engine waste heat. Therefore, this article proposes a new thermal control scheme for pure electric vehicles and conducts corresponding control strategy research. The work done is as follows:

1) Based on the current use status of pure electric vehicle air conditioning, a reasonable battery motor thermal management scheme is proposed, in order to further improve the heating performance of the heat pump air conditioning system for pure electric vehicles, a new type of vehicle thermal management system based on heat pump air conditioning was designed for pure electric vehicles.

2) Divide the functions of the car's thermal management system into different working modes through logical threshold control. There are cockpit temperature control, motor temperature control, and power battery temperature control in different working modes, and fuzzy PID control strategy is used to improve the efficiency of the thermal management system.

3) Simulate and model the vehicle thermal management system designed in this article, and then analyze the modeling results.

In response to the above content, the distribution of chapters in this article is as follows: Chapter 2 mainly introduces the relevant research results of the thermal management system, Chapter 3 elaborates on the design ideas of the thermal function management system scheme, Chapter 4 mainly completes the description of the control strategy of the thermal management system, Chapter 5 mainly analyzes the simulation process and simulation results, Chapter 6 is the conclusion section, and summarizes the shortcomings and further research directions.

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2 Related Work

Mirzabeygi Pooya elaborated on the application of neural networks in predicting thermal performance in vehicles, and provided intelligent management strategies for the control of thermal systems in vehicles [1]. The effectiveness of the method was demonstrated through experiments. There is relatively little research on the internal thermal system of new energy vehicles abroad, while there are relatively many research achievements in China. Weimin Wang et al. re calibrated and matched the functions involved in the development of a heat pump type heat management system, and discussed the determination of various key technical indicators and parameters of the vehicle interior heat management system, which has reference significance for the development of this article's heat management system [2]. Anwen Zhang discussed the thermal management system formed by the overhead air conditioning system of urban pure electric buses, discussed the best solution for internal thermal management, and conducted validation testing on the entire vehicle [3]. Yuanzhi Hu proposed a pure electric vehicle heating system that utilizes motor waste heat to enhance the heating performance of heat pump air conditioning, while heating the battery, in response to the problem of low heating efficiency in pure electric vehicles. Simulation experiments have shown that the new system improves heating efficiency by 27.4% and reduces overall electrical energy consumption by 16.7% [4]. Shaobai Yang described the control principle and scheme of a heat pump controller designed based on the Freescale microcontroller in the system. This system has been successfully operated on a modified vehicle and has undergone a series of verifications to prove the feasibility of the scheme [5].

3 Design of Thermal Management System Scheme

Considering that the overall thermal management system of pure electric vehicles includes three major parts: cockpit thermal management, motor thermal management, and power battery thermal management, as well as the coupling effect of heat from each part, a new overall thermal management system is designed.

3.1 Printing Area

The overall vehicle thermal management system scheme is shown in Fig. 1. The system is mainly divided into the refrigerant circulation part of the heat pump air conditioner, the water circulation part of the motor, and the water circulation part of the power battery [6]. As the research focuses on thermal management systems, the refrigeration cycle of refrigerants will not be discussed. Heat pump air conditioning is mainly composed of components such as a compressor, condenser, expansion valve, evaporator, and gas-liquid separator. When the heat pump air conditioning system is turned on, the refrigerant is compressed into a high-temperature and high-pressure gas state by the compressor, and then flows through each part to release heat before being throttled in the expansion valve. The water circulation part of the motor mainly consists of components such as the motor, water pump, kettle, water PTC, three-way water valve, heating core, and radiator. The water circulation part of the power battery mainly consists of components such as the power battery, water pump, kettle, three-way water valve, liquid heat exchanger, and radiator.

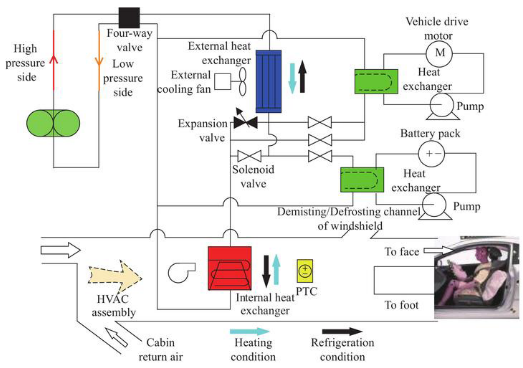


Fig. 1. Vehicle thermal management system solution

3.2 Working Mode of Thermal Management System

The cockpit and motor thermal management are greatly affected by different environmental temperature conditions. According to the heating conditions of the cockpit under different conditions, they can be divided into modes such as motor waste heat assisted heat pump air conditioning heating and motor waste heat assisted PTC heating [7].

1) In the working mode of motor waste heat assisted heat pump air conditioning cockpit heating, the refrigerant cycle of the heat pump air conditioning and the motor cooling water cycle operate simultaneously. This mode is activated when the separate heating performance of the motor waste heat is insufficient, and the motor waste heat is used to assist the heat pump air conditioning in heating the cockpit, improving the energy utilization rate, as shown in Fig. 2.

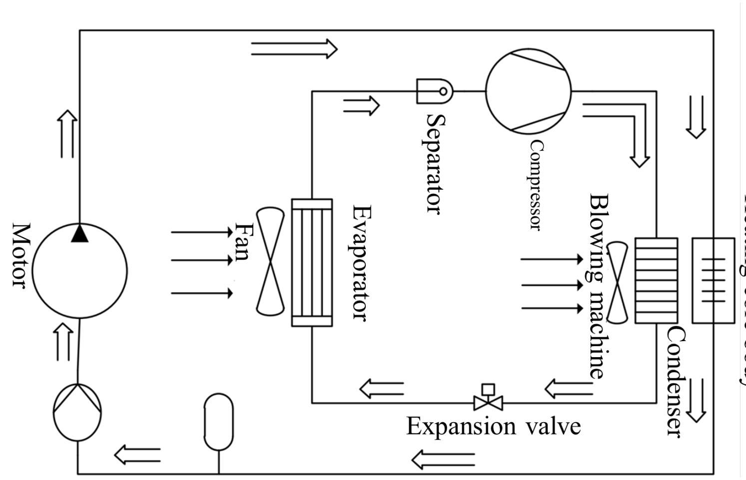


Fig. 2. Motor waste heat assisted heat pump air conditioning passenger compartment heating working mode

The defrosting operation mode of the motor waste heat assisted heat pump air conditioning evaporator is only activated during the heat pump air conditioning heating mode and the evaporator is frosted. After the defrosting is completed, the system automatically returns to the motor waste heat assisted heat pump air conditioning cockpit heating operation mode; If the heat pump air conditioning is not started, even if the evaporator frosts, defrosting will not occur. The working principle diagram is shown in Fig. 3.

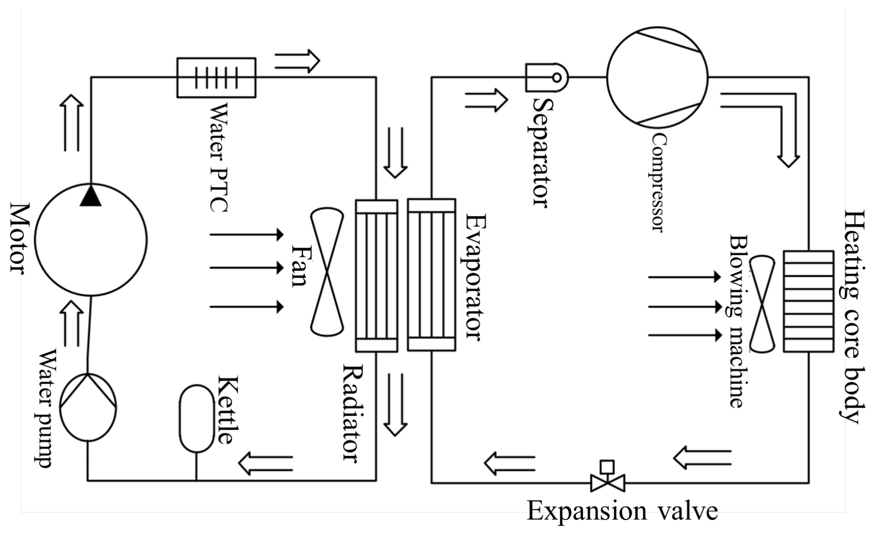


Fig. 3. Motor waste heat assisted heat pump air conditioning passenger compartment heating working mode

2) The motor waste heat assisted PTC heating mode starts with the water pump and PTC heater, and the motor water circulation is shown in Fig. 4. This mode utilizes motor waste heat for heating, mainly using PTC heaters, which are generally only used in extremely harsh working conditions. However, in order to increase the adaptability and stability of the vehicle's thermal management system, this mode is also essential.

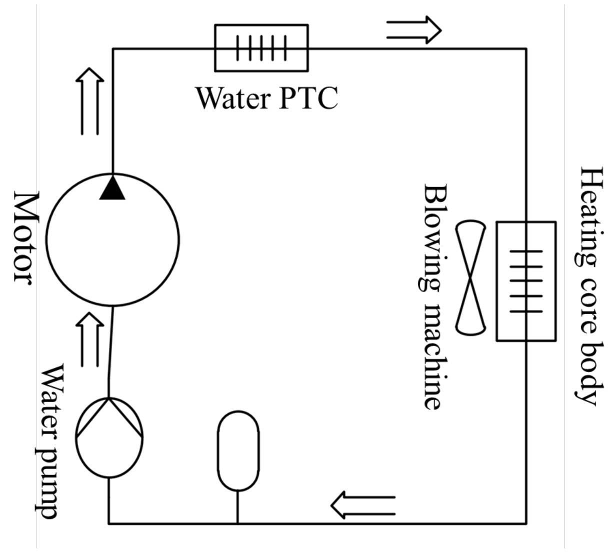


Fig. 4. Motor waste heat assisted PTC heating working mode

After the above process, a new type of pure electric vehicle heat pump air conditioning system assisted by motor waste heat has been completed. This system can reduce the heating power consumption of the heat pump air conditioning by recovering motor waste heat for cockpit heating, and improve the energy utilization rate of pure electric vehicles.

4 Thermal Management System Control Strategy

Design control logic based on the vehicle thermal management plan, propose the influencing factors and components that need to be controlled for the new thermal management plan, and then use PID fuzzy control algorithm to design control strategies for the nonlinear control part of the cockpit thermal system [8].

4.1 Basic Principles of Fuzzy Adaptive PID Control

The block diagram of the fuzzy adaptive PID controller is shown in Fig. 5. Fuzzy adaptive PID control is based on PID control and utilizes fuzzy logic to optimize the parameters of the PID in real-time according to certain fuzzy rules, in order to overcome the shortcomings of traditional PID parameters that cannot be adjusted in real-time.

When the fuzzy adaptive PID controller is working, it first sets an initial set of PID parameters to enable the air conditioning system to operate in an ideal state. When the system experiences instability, the fuzzy adaptive PID controller will calculate the temperature deviation E and the change rate E_C of the deviation based on system feedback. Then, the three system parameters of the PID controller are re determined through the fuzzy controller, The adjusted PID control system can adapt to the new environment and ensure stable operation of the air conditioning system at all times [9].

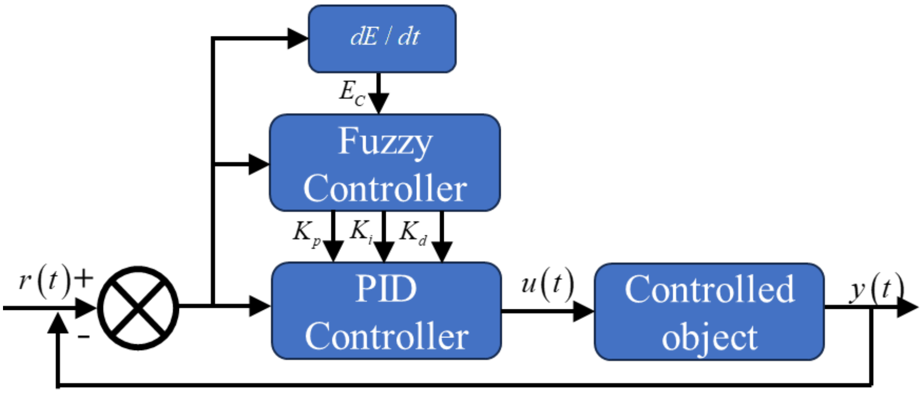


Fig. 5. Schematic diagram of fuzzy adaptive control

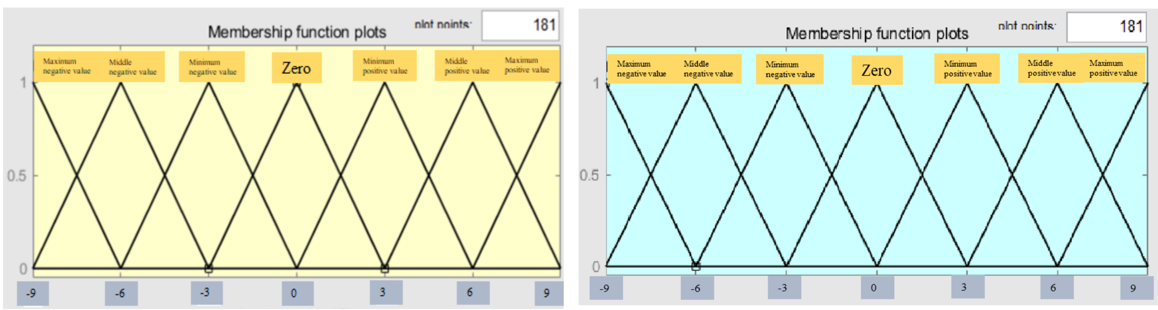
4.2 Basic Principles of Fuzzy Adaptive PID Control

For the control of the compressor speed, PTC power, and *Y* opening of the heating core flow direction in the three-way water valve 3, which regulates the cockpit temperature, this article takes the deviation *E* and deviation change rate E_C between the cockpit set temperature and the actual temperature as control inputs, and adopts a fuzzy adaptive PID control algorithm to achieve good control effect. In winter, the theoretical domain of deviation *E* is [−9, 9], and the fuzzy language representation is shown in Table 1.

Table 1. Fuzzy language set table

Temperature/°C	Fuzzy language
-9	Maximum negative value
-6	Middle negative value
-3	Minimum negative value
0	Zero
3	Minimum positive value
6	Middle positive value
9	Maximum positive value

The domain of deviation change rate E_C is [−3, 3], and the domain of K_p, K_i, and K_d is [−9, 9]. The fuzzy language set is {*NB*, *NM*, *NS*, *ZO*, *PS*, *PM*, *PB*}, which is a Mamdani type controller with two inputs and three outputs. The trigonometric function is used as the deviation, and the membership functions of deviation change rate and K_p, K_i, and K_d are presented. The membership function curves of each input are shown in Fig. 6(a) and Fig. 6(b).



(a) The membership function curve of E_C (b) The membership function curve of K_p, K_i, and K_d

Fig. 6. Input function curve

The fuzzy control rules adopt the "if A and B then C" fuzzy condition statement. Since input E and E_C are composed of 7 fuzzy language variables, 49 fuzzy control rules can be obtained for K_p, K_i, and K_d. The cockpit temperature control varies depending on the heating mode of the control object, and the initial value of the fuzzy PID controller will also vary. The initial PID parameters of the fuzzy PID control are gradually calculated and defined based on the control effect.

5 Simulation Experiment Analysis of Thermal Management System

Establish a control algorithm for the vehicle thermal management model using the Simulink module in MATLAB 2017a software. The vehicle thermal management and controller models are shown in Fig. 7.

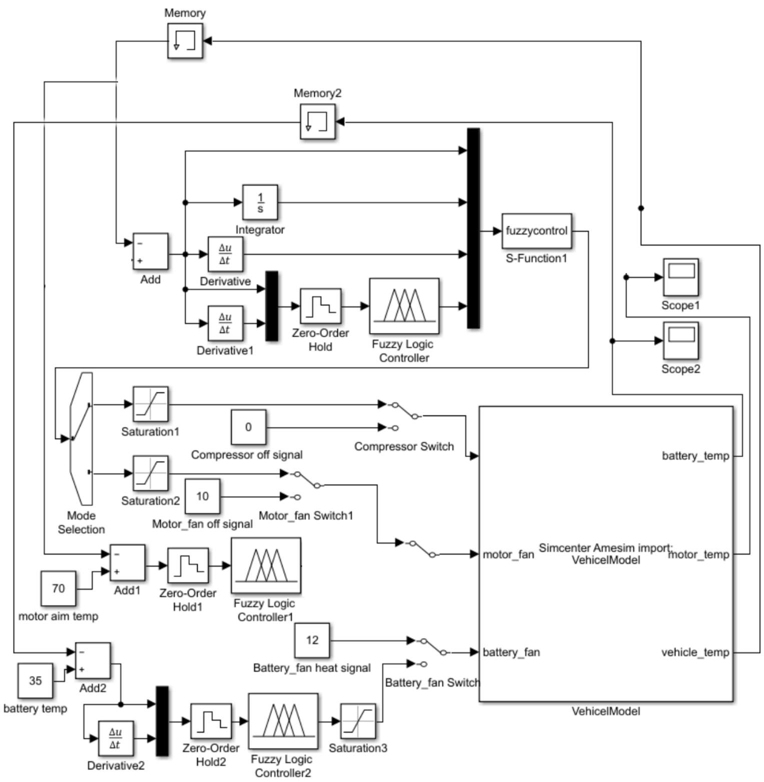


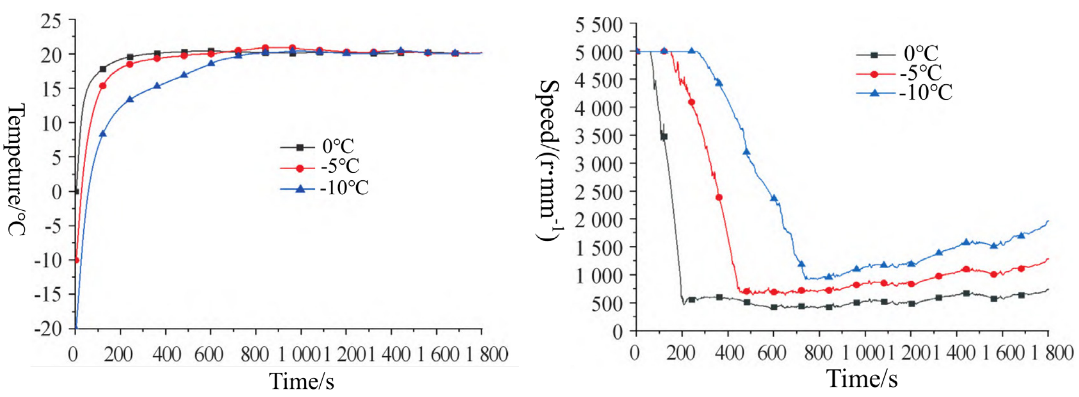
Fig. 7. Control model algorithm

The heating performance of heat pump air conditioning is evaluated by whether the cockpit can reach the set temperature. Due to the fact that the temperature in the cockpit during winter heating needs to be greater than 26 °Cin order for the human body to feel more comfortable, and the upper limit of the temperature setting for general air conditioning is 30 °C, the temperature setting for the cockpit is selected as two simulation conditions: 26 °C and 30 °C. The selection of ambient temperature is shown in Table 2.

Table 2. Heat pump air conditioning passenger compartment heating simulation conditions

Passenger compartment target (°C)	Ambient temperature (°C)	Passenger compartment target temperature (°C)	Ambient temperature (°C)
26	-8	30	-8
26	-4	30	-4
26	0	30	0

The compressor is controlled by a fuzzy adaptive PID controller, and the initial temperature of the cockpit is consistent with the ambient temperature. The simulation operation curve of the temperature change in the passenger cabin and the corresponding compressor speed change curve are shown in Fig. 8(a) when the target temperature set in the passenger cabin is 26 ℃. The simulation operation curve of the temperature change in the passenger cabin and the corresponding compressor speed change curve when the target temperature set in the passenger cabin is 30 ℃ are shown in Fig. 8(b).



(a) Temperature variation curve (b) Compressor speed variation curve

Fig. 8. Control model algorithm

As shown in the above figure, under different ambient temperature conditions, the temperature of the passenger compartment can rise from the initial temperature to the set temperature of 26 ℃. The higher the ambient temperature, the shorter the time it takes for the passenger compartment to reach the set temperature, but the overshoot and compressor speed will also increase. When the ambient temperature is -10 ℃, the time it takes for the passenger compartment to reach the set temperature of 24 ℃ is longer, and the temperature fluctuation is significant. This is because the upper limit of the compressor speed is 7000r/min, At an ambient temperature of -10 ℃, it is close to the heating limit of thermal equilibrium matching, so it is necessary to maintain at maximum speed for a long time to meet the heating demand.

The temperature rise during battery heating at different ambient temperatures is shown in Fig. 9. According to the figure, under one WLTC working condition, the battery was heated in series with the motor coolant and battery coolant, and the temperature of the battery increased from 0, -5, and -10 ℃ to 25.8, 19.3, and 13.5 ℃, respectively. When the ambient temperature is -20 ℃, the increase in battery temperature by more than 0 ℃ and -10 ℃ is due to the increase in internal resistance of the battery at low temperatures, which leads to an increase in self heating during discharge. Moreover, when the battery temperature reaches 15 ℃, the residual heat from the motor is no longer used for battery heating, and the temperature rise of the battery slows down.

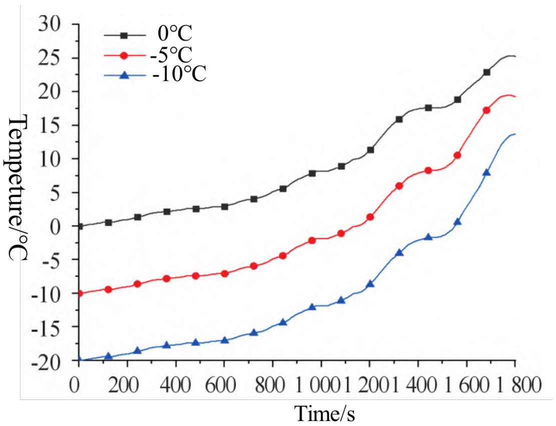


Fig. 9. Temperature rise effect diagram

6 Conclusion

This article proposes a vehicle thermal management system that is suitable for the waste heat of pure electric vehicle motors. The system modeling and simulation analysis were conducted using Matlab software, and it was verified that the system is more energy-efficient and efficient at three different temperatures. However, this article did not consider the performance of the new system at lower temperatures and the issue of heat distribution, and further research is needed. Compared with traditional heat pump air conditioning, the heating time of the passenger compartment is shortened by 27.6%, the heating efficiency of the passenger compartment is increased by 26.3%, the heating effect of the battery is improved by 82.1%, and the electric energy consumption of the entire vehicle is reduced by 17.2% under an ambient temperature of -10 ℃ and one WLTC operating condition of the vehicle. The use of motor waste heat can effectively improve the heating effect of the entire vehicle at low temperatures, reduce heating energy consumption, and provide a way to improve the heating performance of subsequent vehicles and develop control strategies.

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