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Research Article

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Research on automatic shifting of engineering vehicles based on fuzzy control

Zhang Xiaobing, Wang Zhenyu, Miao Lidong

School of Transportation & Vehicle Engineering, Shandong University of Technology, Zibo Zhangdian 255049, China

Abstract Aiming at the problem of automatic transmission control of engineering vehicles, this paper adopts the fuzzy control method based on throttle opening and speed to control the vehicle shift. The engine, torque converter, transmission and vehicle models of engineering vehicles were modeled and simulated in Matlab/Simulink. The simulation results show that it is feasible to apply fuzzy control to automatic transmission and shift of engineering vehicles, and the fuzzy controller can adjust the change of the vehicle shift in time and accurately according to the change of throttle opening and speed.

Keywords Engineering vehicle, AT, Fuzzy control

1. Preface

Engineering vehicles are self-propelled construction machinery with working devices, including bulldozers, scrapers, loaders and other devices, mainly used in construction, mining, railway construction and other fields. The working environment of engineering vehicles is relatively harsh, complex and changeable, resulting in poor fuel consumption and energy efficiency of engineering vehicles. In order to improve the performance of engineering vehicles such as acceleration, operation and other conditions of power and fuel economy. Automatic transmission technology is born from the operation, and automatic transmission technology promotes the improvement of vehicle maneuverability and power [1]. At present, many scholars use intelligent control methods to control transmission, intelligent control methods include fuzzy control, neural network theory control and so on [2]. Among them, intelligent fuzzy control is widely used in the field of automatic transmission of engineering vehicles because of its good adaptive and robust performance [3].

In this paper, the automatic shift system of engineering vehicle is modeled, and a fuzzy shift controller based on speed and throttle opening is designed. Simulation results show that the controller can realize the function of gearshift of engineering vehicle.

2. Engineering vehicle powertrain model

The selected engineering vehicle is the way of hydraulic mechanical transmission, hydraulic mechanical transmission system can effectively reduce the impact load of the parts of the transmission system, reduce the damage of the parts, improve the service life, but also play the function of automatic transmission. It is powered by a diesel engine, passes through a torque converter, transmission and main reducer, and finally drives the wheels [4]. Figure. 1 shows a simplified model of the drivetrain of an engineering vehicle.

Figure 1: Simplified model of engineering vehicle drive system

2.1 Engine model

The engine used this time is a diesel engine, and its output torque is a function of speed and throttle opening. According to the data of steady-state torque of the engine, the external characteristic model and the speed regulation model of the engine in steady-state can be fitted[5]. The external characteristic model of the engine is as follows:

$$T_e = -3.5233 \times 10^{-4} n_e^2 + 1.1097 \times n_e + 95.1573 \quad (1)$$

T_e is the output torque of the engine, $\mathrm{N \cdot m}$; n_e is engine speed , $\mathrm{r/min}$;

The speed regulation characteristic model of the engine is as follows:

$$T_e = -4.9976 n_e + 11982\alpha \quad (2)$$

T_e is the output torque of the engine, N·m; n_e is engine speed ,r/min; α is the engine throttle opening;

In the actual working process, most of the time, the vehicle is in dynamic conditions, and the data under steady state conditions cannot accurately reflect the actual situation, so the dynamic characteristic formula of the engine is often used, as shown below:

$$T_{ed} = T_e - J_e \dot{\omega}_e \quad (3)$$

T_{ed} is the dynamic output torque of the engine, N·m; J_e is the engine moment of inertia $\mathrm{kg \cdot m^2}$; $\dot{\omega}_e$ is the angular acceleration of the engine $\mathrm{rad \cdot s^{-2}}$;;

2.2. Torque converter model

The dynamic model of the torque converter is:

$$M_B = \rho g \lambda_B n_B^2 D^5 \quad (4)$$

$$M_T = K M_B \quad (5)$$

$$n_B = n_e \quad (6)$$

M_B is the torque of the torque converter pump wheel, N·m; ρ is the oil density of the working medium at the working oil temperature, $\mathrm{kg/m^3}$; g is the acceleration of gravity, $\mathrm{m/s^2}$; λ_B is the torque coefficient of the pump wheel of the torque converter. n_B is the pump wheel speed, r/min; D is the effective diameter of the torque converter cycle circle, m; K is the torque coefficient of the hydraulic torque converter; M_T is the torque of the torque converter turbine, N·m.

The original characteristic curve of hydraulic torque converter is composed of three important dimensionless characteristic curves of pump wheel torque coefficient, torque coefficient and efficiency, which reflects the change law of pump wheel torque coefficient λ_B, efficiency η and torque coefficient K with the speed ratio i. According to the original characteristic data obtained by relevant tests, the original characteristic equation can be obtained by fitting the formula, as shown below:

Torque ratio:

$$K = -0.9759 i^4 - 3.4962 i^3 + 8.6085 i^2 - 7.5084 i + 3.7327 \quad (6)$$

Efficiency:

$$\eta = -6.3474 i^4 + 11.5425 i^3 - 8.7174 i^2 + 3.8889 i - 0.0032 \quad (7)$$

Torque coefficient:

$$\rho \lambda_B \times 10^4 = -137.0319 i^4 + 208.4054 i^3 - 108.0646 i^2 + 20.0694 i + 14.8611 \quad (8)$$

2.3. Power shift transmission model

The transmission model selected this time is a power shift transmission with a certain shaft. According to the power needs, the transmission ratio of different gears of the transmission can be changed, and the kinematics and dynamics models of the transmission can be obtained:

$$n_T = i_g n_2 \quad (9)$$

$$M_2 = i_g M_1 \quad (10)$$

$$M_1 = M_T \quad (11)$$

n_T is the transmission turbine speed, r/min; i_g is the transmission ratio of each gear; n_2 is the speed of the transmission output shaft, r/min; M_2 is the torque of the transmission output shaft, N·m; M_1 is the torque of the transmission input shaft, N·m;

The speed changes of each gear are shown in the table 1 below.

Table 1: Gear Ratio

Gear	Gear Ratio
1	5.883
2	3.100
3	1.444
4	0.887
5	0.762

2.4. Vehicle dynamic model

The power output of the gearbox is transmitted to the wheels through the drive shaft and the main reducer to overcome the resistance of the car body and the outside world, including rolling resistance, air resistance, slope resistance and acceleration resistance. The driving formula of the vehicle is as follows:

$$F_t = F_f + F_w + F_i + F_j \tag{12}$$

Or

$$\frac{T_T i_0 i_g \eta_z}{r} = mgf + \frac{C_D A v^2}{21.15} + mgi + m\delta\frac{dv}{dt} \tag{13}$$

F_t is the driving force, N; F_f is rolling resistance, N; F_w is air resistance, N; F_i is slope resistance, N; F_j is acceleration resistance, N; T_T is the output torque of the torque converter turbine, N·m; i_0 transmission ratio of the main reducer; i_g is the transmission ratio of the transmission; η_z is the transmission efficiency from transmission output shaft to drive wheel of construction vehicle; r is the radius of the tire, m; m is the mass of engineering vehicle, kg; g is the acceleration of gravity, $\mathrm{m/s^2}$; f is rolling resistance coefficient; C_D is the air resistance coefficient; A is the windward area of the vehicle, $\mathrm{m^2}$; v is the vehicle speed, km/h; i is the slope; δ is the conversion coefficient of vehicle rotating mass.

3. Establishment of fuzzy variable speed controller

The design of fuzzy controller is to determine the input variables and output variables of fuzzy controller. Usually, the number of input variables of fuzzy controller is called the dimension of fuzzy controller. The higher the dimension of fuzzy controller, the finer the control. However, if the dimension is too high, the fuzzy control rules will become very complicated and it is relatively difficult to realize the control algorithm. Therefore, the two-dimensional fuzzy controller designed in this paper is the core of the entire control system. The automatic shift fuzzy controller is composed of multiple knowledge base modules such as fuzzy, fuzzy reasoning and anti-fuzzy, and its working principle is as follows: The fuzzy controller collects various signals of the vehicle, such as throttle opening, engine speed, turbine speed, gear position, etc. Through the analysis of various parameters, the controller can identify the working condition of the system and decide whether to shift according to the shift law, so as to ensure the highest efficiency and optimal performance of the transmission system. In this paper, throttle opening and speed are selected as input variables, and transmission gear i is selected as output variable, that is, a two-dimensional fuzzy controller block diagram with dual-input and single-output structure is obtained as shown in the following figure.

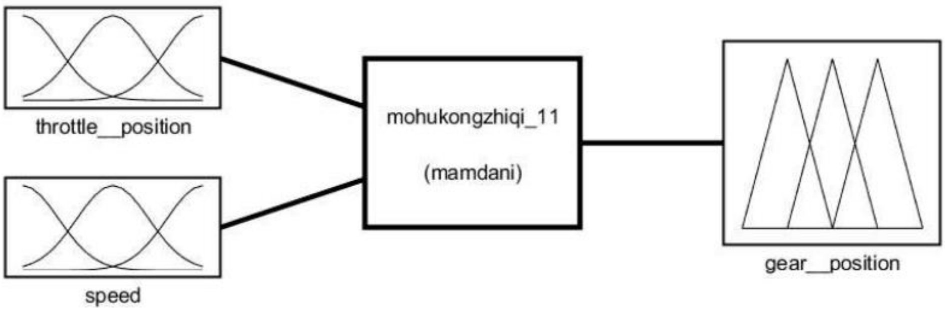

Figure 2: Two-dimensional fuzzy controller

3.1. Determination of input and output variable domains

The real domain of the input (i.e. the range of variation) is transformed into the internal domain of the fuzzy controller. Transform the throttle opening to the internal domain as {0,10,20,30,40,... , 100}, the speed of transform domain{0,5,10,15,20,25,30} to internal theory, theory of gear internal domain {0,1,
2,3,4,5 }.

3.2. Fuzzification

In this part, the precise input of the system is converted into a fuzzy quantity, and the input parameter throttle opening α is converted into 7 fuzzy sets, which include 7 fuzzy sets for input α : very small (VS), very small (MS), small (S), medium (M), large (B), very large (MB), and very large (VB). The input parameter vehicle speed u is transformed into 7 fuzzy sets, which include 7 fuzzy sets for input u: very small (VS), very small (MS), small (S), medium (M), large (B), very large (MB) and very large (VB). The output gear has 5 fuzzy sets, 1, 2, 3, 4, 5 fuzzy sets.

3.3. Defines membership functions for language variables

The fuzzy control system can deal with fuzzy parameters, but the input parameters are still definite clear parameters, so it is necessary to use membership function to transform the clear variables into fuzzy variables, after which the fuzzy control system can carry out related logic processing of fuzzy parameters.

For engineering vehicle throttle opening α, its membership function can be selected as normal membership function, and the membership of each subset is set as shown in the figure below:

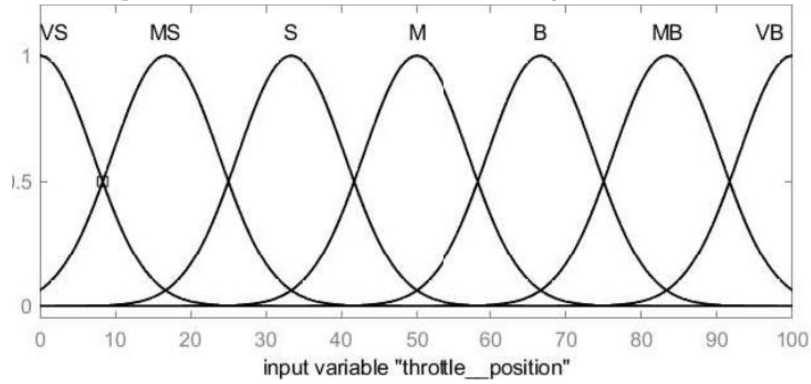

Figure 3: Throttle opening membership function

For the speed of engineering vehicle v, its membership function can be selected as normal membership function, and the membership of each subset is set as shown in the figure below:

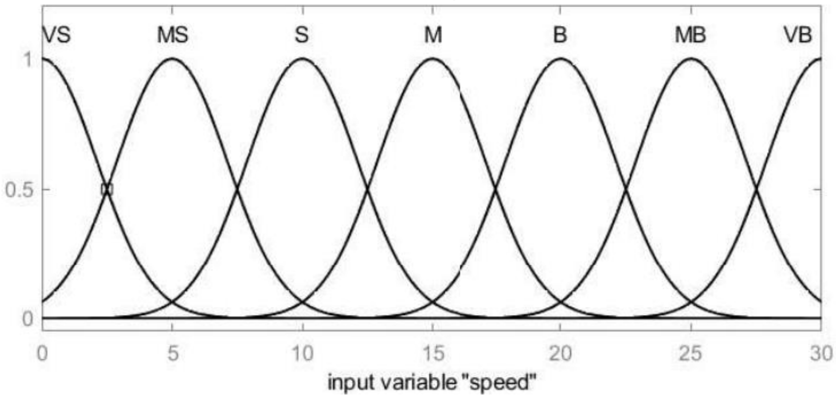

Figure 4: Vehicle speed membership function

For the output gear d of the transmission, the membership function of the triangular membership function can be selected, and the membership Settings of each subset are shown as follows:

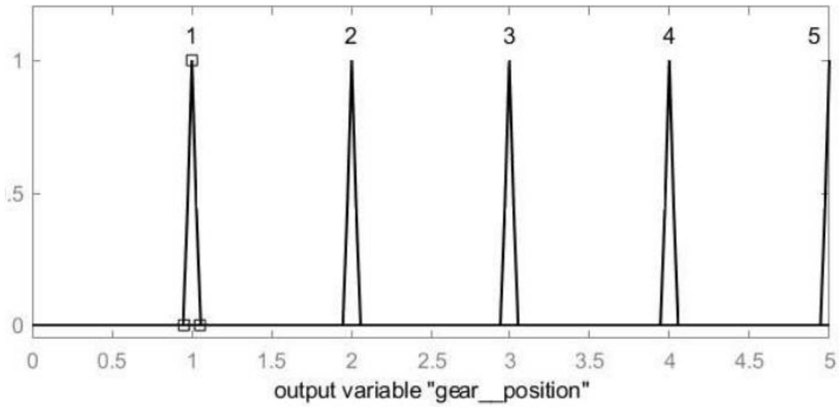

Figure 5: Gear membership function

3.4. The establishment of fuzzy control rules

The control rule of the fuzzy controller is based on the manual control strategy, and the manual control strategy is based on the accumulation of the driver's operating experience. In order to ensure the high efficiency of the hydraulic torque converter, the controller with two inputs is adopted in this paper. The input parameter throttle opening takes 7 linguistic values, and the speed takes 7 linguistic values, so the number of control rules is 49. The specific fuzzy control rules are shown in the following table 2.

Table 2: Fuzzy control rule

	VS	**MS**	**S**	**M**	**B**	**MB**	**VB**
VS	1	1	1	2	3	4	5
MS	1	1	2	2	3	4	5
S	1	1	2	2	3	4	5
M	1	2	2	3	3	4	5
B	1	2	3	3	4	4	5
MB	1	2	3	3	4	4	5
VB	1	2	3	3	4	4	5

In this paper, Mamdani direct inference method is used for fuzzy inference, and Min-Max-gravity center method is used for defuzzification. The fuzzy shift surface is shown in the figure.

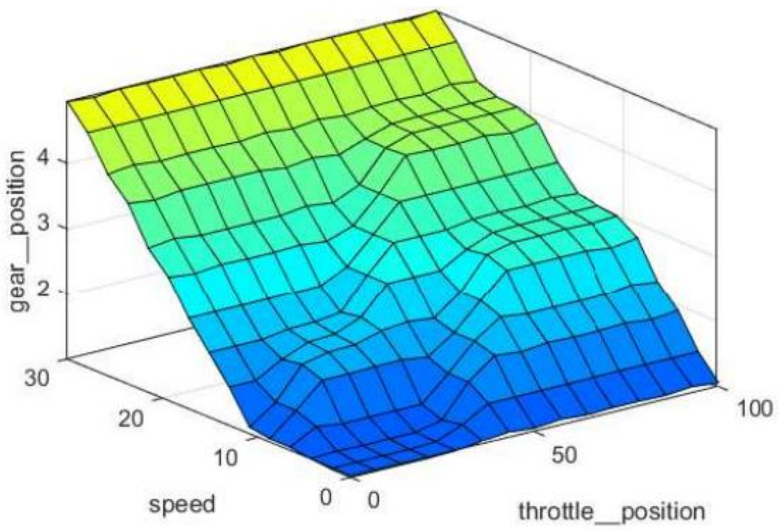

Figure 6: The fuzzy shift surface

4. Simulation Results and Analysis

In order to verify the correctness of the above shift law, a Matlab/Simulink simulation model based on fuzzy control is established according to the mathematical model of the engineering vehicle's power transmission system. As shown in the following picture.

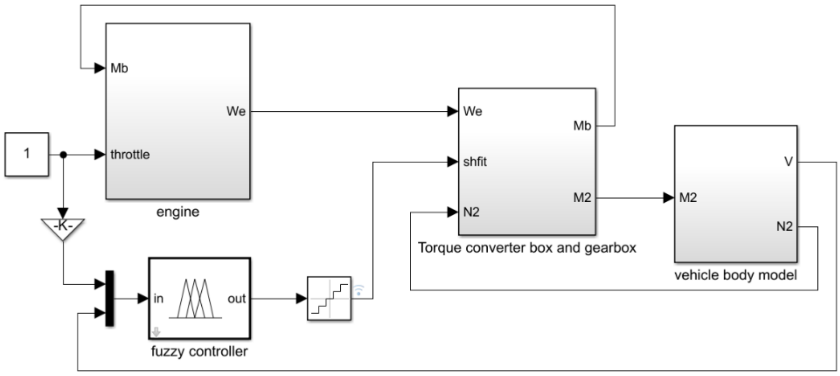

Figure 7: Simulation model

In the actual running process of the vehicle, the driver will make a reasonable response to the throttle opening and braking force according to the actual situation. For the convenience of the model, only the throttle opening signal of the engine is considered as the input of the simulation, and the corresponding changes caused by changes in other factors are not considered.

The initial acceleration condition is simulated, and the initialization conditions are set as follows: the input condition is throttle opening α = 100%, the simulation time t =50s, and the initial vehicle engine speed n_e=800 (r/min).

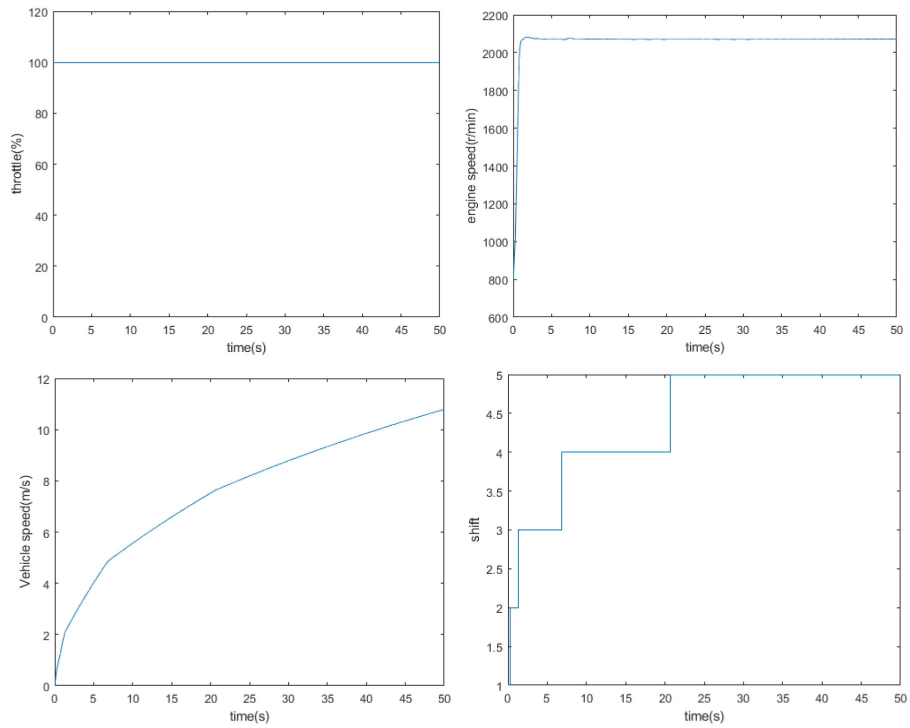

Figure 7: Simulation result

As shown in the figure, it is the simulation result of the starting acceleration condition. As can be seen from the figure above, at the beginning of the simulation, the throttle opening of the engine is maintained at 100%, the engine speed n_e rapidly increases from the initial 800 r/min to the highest speed and maintains high-speed operation, and the vehicle speed continues to increase. The fuzzy controller can realize automatic shift according to the throttle opening and speed, realizing the function of automatic transmission.

5. Conclusion

According to the working characteristics of engineering vehicles and the problem of automatic transmission, a fuzzy controller with multi-input and single-output structure is developed from the model of engine, torque converter, gearbox and vehicle. The simulation test is carried out under certain initial conditions. The results show that the automatic transmission model based on the fuzzy control of throttle opening and speed can realize the automatic transmission function of vehicle.

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