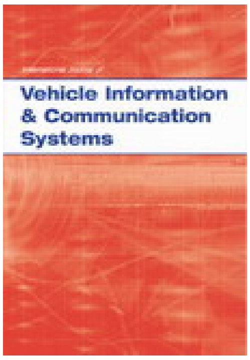

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Vehicle parallel integrated control strategy based on coordinated SAS and ABS

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Vehicle parallel integrated control strategy based on coordinated SAS and ABS

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Abstract: In order to improve the braking performance and ride comfort of vehicles, a parallel integrated control strategy based on the coordinated statistical analysis system (SAS) and the anti-lock braking system (ABS) was studied. The simulation experimental results show that when using the control strategy designed in this study, the time required for the subjects to enter steady state from the beginning of the working process is about 0.05 to 0.06 seconds, and there is no overshoot phenomenon during the working process. However, when using the strategies given in literature, the process takes 0.12 seconds and overspeed may occur. The designed control strategy has better braking performance, effectively improving the overall performance of the vehicle, and significantly reducing the energy loss area compared to traditional methods.

Keywords: SAS; ABS; automobile control; parallel integrated control; fuzzy control.

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1 Introduction

The safety and comfort of automobiles are the two major objectives of the development of automobile chassis technology. At the same time, domestic and foreign experts and scholars have made a great deal of research in the field of safety and comfort of automobiles by using the electronic control technology of chassis. The Electronic Stability Program (ESP), Antilock Brake System (ABS) and 4Wheel Steering System (4WS) and other technologies are all of great significance to improve the safety and handling stability of automobiles. At the same time, the development of technologies such as active/semi-active suspension has also made important contributions to improve the riding comfort and comfort of automobiles. The automobile chassis is a whole, and each electronic control module has its own control objectives. Therefore, the integrated control of chassis is an important way to realise the coordinated control of multiple objectives of chassis (He et al., 2019; Guerrero et al., 2020).

Under such working conditions as braking and downhill, the energy recovery system will exert additional force on the vehicle due to the recovery of the kinetic energy or potential energy of the vehicle, and its effect will directly affect the braking or driving performance of the vehicle. If the braking or driving control system fails to take this additional force factor into full account, the stability control of the vehicle will be interfered and the vehicle will then be unstable (Wu et al., 2019; Abrehdari and Sarvi, 2019). Suspension systems and anti-lock systems (ABS) play an important role in controlling the stability of vehicles under conditions such as braking and downhill (Xin et al., 2018; Zhang et al., 2018). Therefore, how to control the suspension and ABS system and maintain the stability of the vehicle will be an urgent problem to be solved in the process of vehicle research. Neural network and fuzzy control are usually used to realise the coordinated distribution of regenerative braking force and hydraulic braking force in the study of vehicle energy recovery and stability control strategy at home and abroad, while the vehicle stability control strategy is mainly based on the separate control strategy of vehicle suspension and ABS system (Zhang et al., 2018; Wang et al., 2018a, 2018b).

In order to improve the braking and riding comfort of vehicles, this research innovatively proposes a parallel integrated vehicle control strategy based on the coordination of SAS and ABS. The relationship between energy recovery and stability control is studied by establishing the chassis parameter model. Based on the control parameters of battery, voltage and fuel consumption, an integrated control strategy for energy recovery and vehicle stability of parallel vehicles is designed, which is the main contribution of this research to the industry.

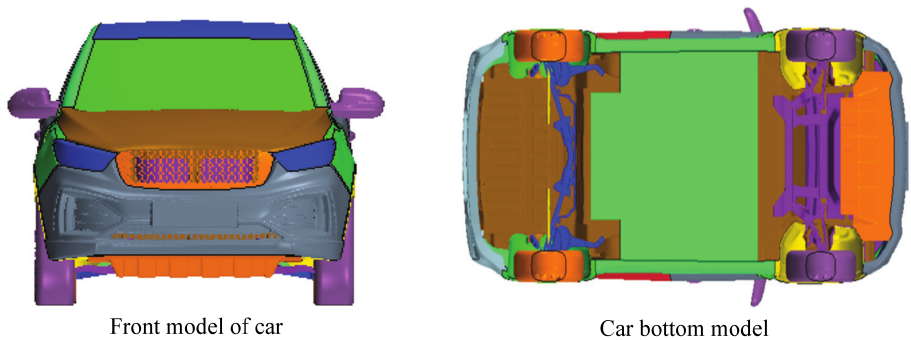
2 Vehicle parallel integrated control based on coordinated SAS and ABS

2.1 Construction of parametric model of automobile chassis

Firstly, the framework of this research is described. First, a parametric model of the vehicle chassis is built, and then the relationship between the vehicle energy recovery and stability control is analysed based on this model. Then, the comprehensive control strategy of energy recovery and vehicle stability of parallel vehicles is completed through the relationship conclusions and the parametric model of the vehicle chassis. Next, we will introduce the process of building the parametric model of the automobile chassis. In order to establish the parametric model of the rear half of the chassis structure, firstly, the relationship between the chassis structure and the external environment flow field is analysed through the geometric model, and then the relationship between the basic parameters of the rear half of the chassis structure and the vehicle performance is determined by integrating the wind tunnel model (Furnémont et al., 2018; Nobile et al., 2019).

The geometric model of the car is shown in Figure 1 as follows.

Figure 1 Vehicle geometric model



In order to make the data simulation of automobile outflow field scientific and authentic, this paper adopts the rear structure of automobile chassis with the highest sales of different brands as the research model. Because the real field simulation will cause harm to personnel, the model is adopted for analysis. The model is a vehicle model of the same material one-to-one ratio size. In order to restore the performance of the vehicle to the maximum extent, the ratio of the length and width of the wind tunnel model to the length and width of the vehicle model is 6 to 1, and the ratio of the height is 10 to 1. In this paper, the size of the vehicle model is 4.00 meters × 1.70 meters × 1.50 metres, and the wheels and the floor are set to move automatically, and the vehicle speed is always maintained at 120 km/h (Ren et al., 2020). In the rear chassis structure, the front and rear doors, moving glass, bumpers near the chassis and the connecting parts between the components of the rear chassis have the strongest influence on the outflow field. After the wind tunnel model and simulation of the car model, the chassis of the pipeline and line optimisation to promote the second half of the car cycle, improve the car's engine performance.

The parameterised finite element model is mainly used to divide the vehicle structure into cells, to calculate the numerical value of vehicle flow field, and to provide the data analysis basis for vehicle structure analysis. Firstly, the chassis structure is divided into three parts, then the upper, middle and lower parts are formatted and cut, and the welded gap of the chassis structure is divided into rigid cells. Regardless of the size of the mesh of the parameterised finite element model, the number of cells is not standardised, and only the vehicle structure is divided to ensure the rationality of the chassis structure analysis. The three layers of the chassis structure are all divided by shell cells of a uniform type. Once a problem of the chassis frame is calculated by a pneumatic model, the scope of the structure is narrowed according to a parameterised finite model (Liu et al., 2020; Sun et al., 2019)

After the rear part of the chassis is reasonably divided, the parametric finite element model is established in this paper. The detailed variables of different structures are defined, and the detailed variables of each structure of automobile chassis are shown in Figures 2 to 4.

Figure 2 Detailed design of front cross-member of automobile chassis

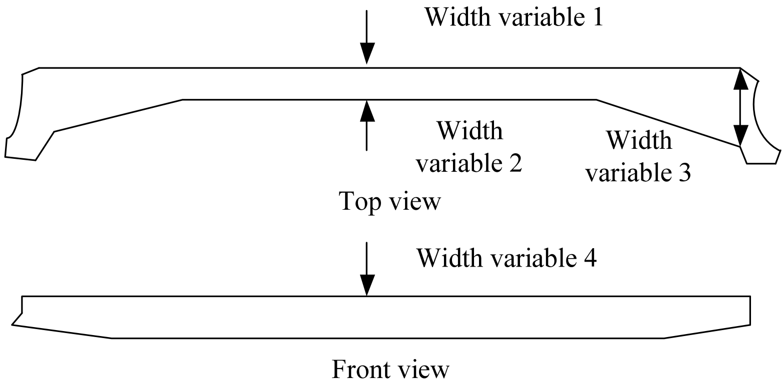
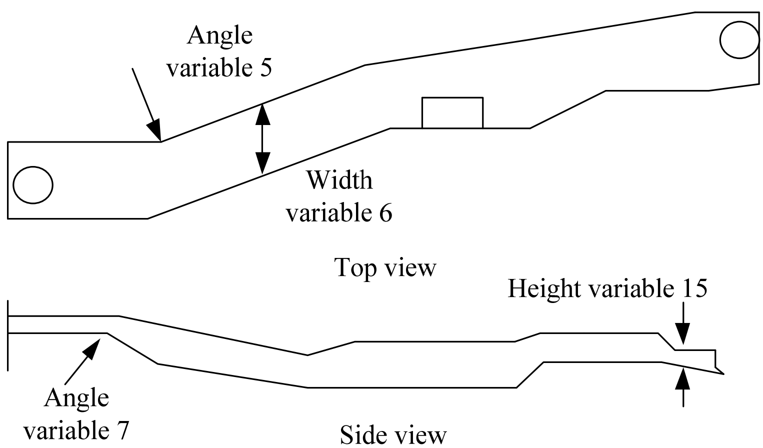


Figure 3 Detailed analysis of longitudinal and transverse beams of automobile chassis



The automobile chassis is mainly composed of five main structures: front cross-beam, longitudinal arm, front cross-beam, back cross-beam and reinforced solder pad. The main elements of the structure are the size of the structure, thickness, cross-section area of the structure, the building area of each structure, the location and space of the structure. In this paper, we use the computer drawing software to complete the simulation frame of the automobile chassis, and make the characteristic points of the rear half structure of the automobile chassis into variable values, each variable value sets a certain range of values, which provides convenience for the later calculation (Shu et al., 2018; Shan et al., 2019). The range of values for each variable is the range of values for the design and measurement of the chassis of a parameterised finite model of an automobile, which is reasonably determined on the basis of the chassis structural size, structural position and spatial position, as shown in Table 1.

Figure 4 Detailed design of rear cross-member of automobile chassis

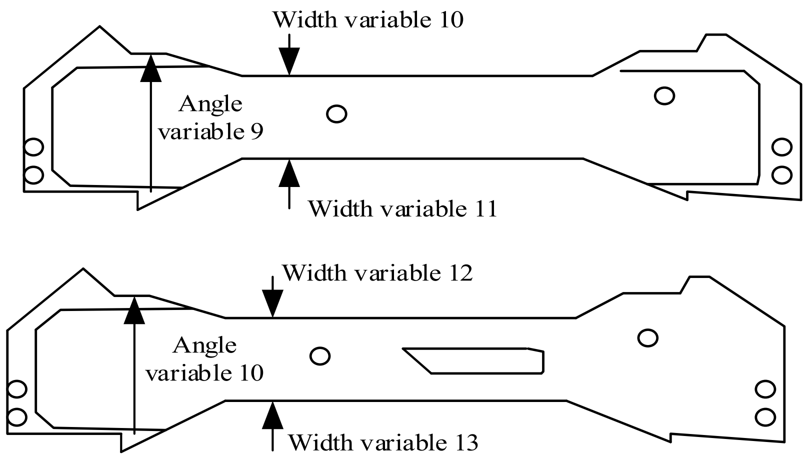


Table 1 Variable value range

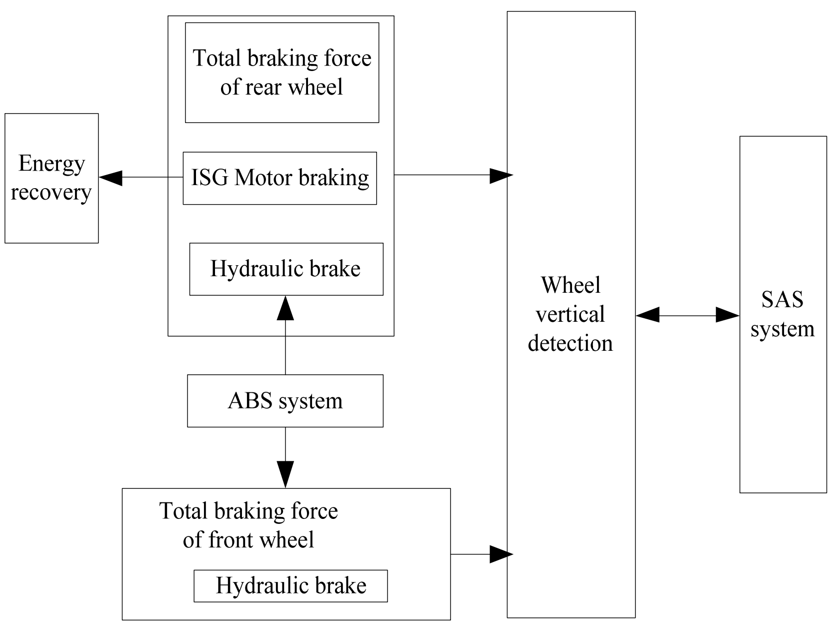
Variables	*Value range*	*Variables*	*Value range*
1	–10–10	15	0–7
2	–15–30	16	0–3
3	–10–30	17	0–70
4	0–10	18	1.6, 1.9, 2.2, 2.5
5	0-3	19	2, 2.2, 2.5, 2.8
6	–15–15	20	2.5, 2.8, 3.0, 3.2
7	0–3	21	2, 2.2, 2.5, 2.8
8	0–10	22	1.8, 2, 2.2, 2.5, 3
9	0–15	23	1.8, 2, 2.2, 2.5, 3
10	0–10	24	16, 1.9, 2.2, 2.5
11	–30–20	25	16, 1.9, 2.2, 2.5
12	0–15	26	1.6, 1.8, 2.0, 2.2, 2.8
13	0–15	27	1.6, 1.9, 2, 2.2, 2.5
14	0–105	28	2, 2.2, 2.5, 2.8

2.2 Relationship between energy recovery and stability control

The energy recovery system of paralleled vehicle usually works under the conditions of braking, downhill and idling. The generator is used as the main part of energy recovery to convert the surplus energy of the vehicle into electric energy and store it. At the same time, it can produce some auxiliary braking function. When the energy is recovered, the auxiliary braking force will change the original braking distribution of the vehicle, thus affecting the power composition and stability of the vehicle (Tao et al., 2018). Therefore, when considering the energy recovery control strategy, it is necessary to consider comprehensively the energy recovery efficiency and vehicle stability. Through the analysis of the structure of the parallel vehicle energy recovery system, the power system, brake system, ABS system and SAS system are involved in the energy recovery and stability control of the vehicle. As is shown in the diagram, the ABS system plays a coordinating role in the distribution of the total braking force between the front wheel and the rear wheel. The total braking force consists of ISG motor braking and hydraulic braking. The ISG motor recovers the braking force while providing the braking force. Therefore, in the process of energy recovery, the distribution of the braking force between the front wheel and the rear wheel is involved in the distribution of the electro-hydraulic braking force between the front wheel and the rear wheel. At the same time, if the distribution of the braking force between the rear wheel and the rear wheel is not reasonable, the distribution of the braking force between the front wheel and the rear wheel will affect the whole vehicle.

At the same time, if the rear wheel braking force distribution is not reasonable, it will affect the whole vehicle’s front and rear wheel braking distribution, and then cause the vehicle’s vertical load distribution of the front and rear wheels to be uneven, and cause the vehicle to brake ‘nod’, and drive unstable (Yang et al., 2020). In this case, the SAS system, which is used to control the vehicle’s ride comfort, needs to control the damping force of each wheel suspension to eliminate the vehicle’s jitter. Therefore, how to reasonably distribute the wheel-hydraulic braking force and recover the energy to the greatest extent while maintaining the stability of the parallel vehicle needs to coordinate and control the running state of each system of the parallel vehicle so as to make the vehicle more economical and stable.

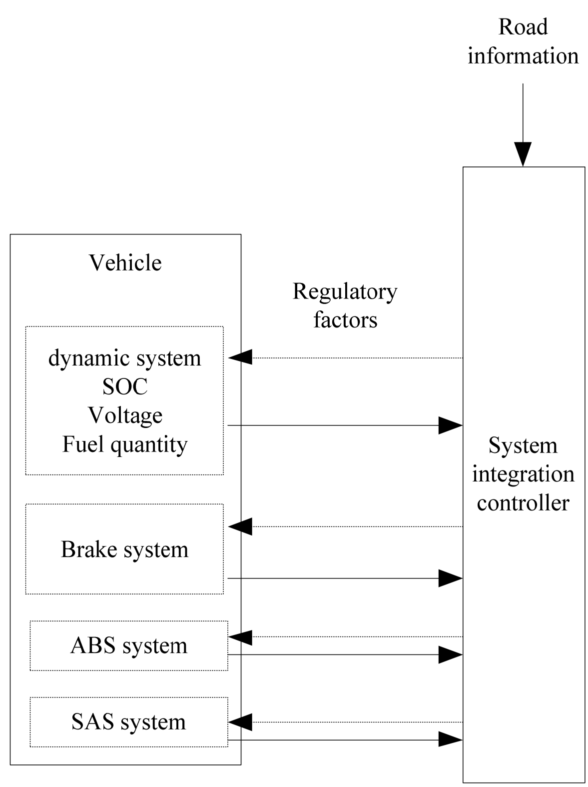
Figure 5 Relationship between energy recovery and stability control of parallel vehicle



2.3 Integrated control strategy

Figure 6 shows a diagram of the integrated control strategy for the energy recovery and vehicle stability of a parallel vehicle. The system integration controller analyses and judges the battery, voltage and fuel of the power system, the total brake hydraulic pressure of the ABS system and the brake hydraulic pressure of the four wheels (front left/front right/left/rear/right), the pedal stroke of the brake system and the vehicle speed, acceleration, wheel speed of the four wheels (front left/front right/left/right) of the parallel vehicle, the roll angle of the vehicle body, the vertical load of the four wheels (front left/front right/left/rear right), the tilt angle of the vehicle body and the Az information of the vertical acceleration of the body mass centre, and obtains the driver control signals and road information, which are input into the integrated coordination controller of the system for processing. Finally, different output adjustment factors are fed into the power system, the ABS system, the brake system and the SAS system, which provide reference for the control of each subsystem. There are corresponding ECU modules in each subsystem, and they can communicate with each other, which makes the controller of each subsystem interact with the controller of the system.

Figure 6 Schematic diagram of integrated control strategy for energy recovery and vehicle stability of parallel vehicle



The power system is the main executive unit of the parallel vehicle energy recovery system. In order to ensure the safety of the vehicle, the energy recovery process must be carried out under the specific vehicle conditions, working conditions and road conditions, usually under the conditions of braking, downhill and idling and needs to consider the battery power and other information comprehensively. In the first section, the rules of energy recovery are analysed. In this paper, the threshold control strategy is used to determine the different braking forms. In the hybrid braking form, the integrated control strategy is used, which is realised by adjusting factor K_{power} so as to effectively and reasonably control the power distribution, maximise the use of motor braking, realise the effective recovery and utilisation of energy and ensure the stable running of vehicles.

Under the action of inertia, the vertical load on the front wheel increases and the vertical load on the rear wheel decreases, which means ‘nod’, while the SAS system can absorb and release the vertical load on the four wheels by controlling the stepping motor in the shock absorber (Abut and Soyguder, 2019; De et al., 2018). In order to prevent ‘nod’ and other phenomena, it is necessary to improve the vertical load of wheels, coordinate the control of braking force on 4 wheels and the distribution of suspension damping force. The brake system and the ABS anti-lock system are usually used to control the four-wheel hydraulic braking force distribution. Therefore, the ABS system and the SAS system are the objects of stability control.

Both SAS system and ABS system adopt fuzzy control strategy to output damping force of four shock absorbers and braking torque of four wheels respectively. Compared with conventional fuzzy controller of SAS system and ABS system, two error terms e_{SAS} and e_{ABS} are added in input parameters to optimise the distribution of front and rear wheel suspension damping force and braking force. The calculation formula of the two error terms is as follows.

$$e_{SAS} = k_{SAS} - \left(F_{damper,bank} / F_{damper,total}\right) \tag{1}$$

where k_{SAS} is the ratio of the damping force of the rear wheel shock absorber calculated by the system integrated controller to the total damping force of the four shock absorbers; $F_{damper,bank}$ is the actual damping force of the rear wheel shock absorber; $F_{damper,total}$ is the actual total damping force of the four shock absorbers.

$$e_{ABS} = k_{AbS} - \left(T_{bra\,\mathrm{ker},bank} / T_{bra\,\mathrm{ker},total}\right) \tag{2}$$

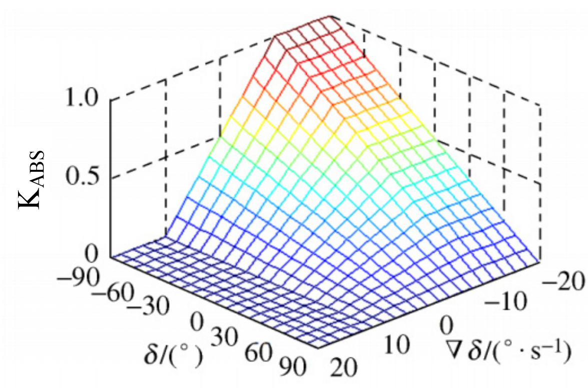
where e_{ABS} represents the ratio of the rear wheel braking torque and the total braking torque calculated by the system integrated controller; $T_{bra\,\mathrm{ker},bank}$ represents the actual rear wheel braking torque; $T_{bra\,\mathrm{ker},total}$ represents the actual total braking torque of the four shock absorbers.

Among all the regulation factors, the regulation factor K_{power} of the power system acts on the control of the power system, which is directly related to the energy recovery efficiency and vehicle stability:

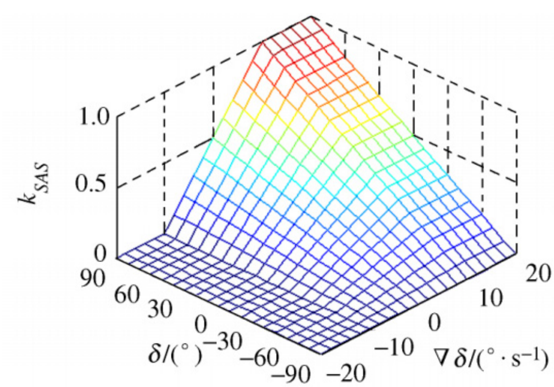
$$K_{t\arg et} = K \times k_{power} \tag{3}$$

where K is the ratio of motor braking torque and rear wheel total braking torque, $K_{t\arg et}$ is the optimised braking torque ratio. The purpose of setting the adjustment factor k_{power} of the power system is to optimise the distribution ratio of motor braking torque and hydraulic braking torque, so as to coordinate and control the relationship between braking energy recovery efficiency and vehicle stability. Because the SOC value of battery can directly reflect the recovered energy and power consumption, and the vehicle longitudinal tilt angle δ can monitor the vehicle state in real-time, and its rate of change δ can reflect the stability of vehicle driving, so the SOC value and rate of change δ are selected as inputs, and a comparison threshold a (a is taken as 2°/s) is set for the rate of change δ, and the rate of change δ is quantified as δ / A. According to the fuzzy control reasoning, the optimal braking force ratio $K_{t\arg et}$ can be obtained by outputting k_{power} value.

Figure 7 K_{ABS} and K_{SAS} value curve (a) K_{ABS} value curve (b) K_{SAS} value curve



(a)



(b)

The adjustment factor $k_{bra\ker}$ of the brake system is a parameter which depends on the driver control, vehicle condition and road information. It is used to optimise the total braking torque of the parallel vehicle and ensure the braking stability of the vehicle. According to the road identification and driver active control, the corresponding relationship between the total braking moment $T_{bra\ker,total}$ and the brake pedal stroke under different road conditions is set. However, because the control strategy such as road identification is not set in this system, the value of $k_{bra\ker}$ is 1 in this paper.

3 Simulation experiment design and result analysis

CarSim software and Simulink software are used for CO simulation. The initial vehicle speed is 80 km/h, and other main simulation parameters are shown in Table 2.

Table 2 Main simulation parameters

Model parameter	*Numerical value*
Body mass/kg	1274
Front wheel mass/kg	35.5
Rear wheel mass/kg	35.5
Front suspension stiffness /($N \cdot mm^{-1}$)	27
Rear suspension stiffness / ($N \cdot mm^{-1}$)	30
Wheelbase /mm	2578
Centroid height /mm	540
Tire size	205/55/R16
Front wheel stiffness / ($N \cdot mm^{-1}$)	228
Rear wheel stiffness / ($N \cdot mm^{-1}$)	228

The curves of XOZ plane left front wheel force and angle α varied with time are shown in Figures 8 and 9, respectively. As can be seen from Figure 8, the tire force FC increases rapidly from 4200 to 5400 N when braking, and fluctuates from about 5400 N in the first 4 seconds. The tire force FC drops sharply in 4 to 5 seconds, and the tire force recovers to 4200 N when the vehicle stops. As can be seen from Figure 4, the horizontal angle α of the FC maintains a small fluctuation around –1.25° after braking, and when approaching the end of braking, the angle fluctuates twice instantaneously and eventually stabilises at 1.5°.

The braking distance curve is shown in Figure 10. In Figure 10, the solid line is the braking distance curve under ABS control only, and the dotted line is the braking distance curve under integrated control.

Figure 8 Curve of tire force FC with time

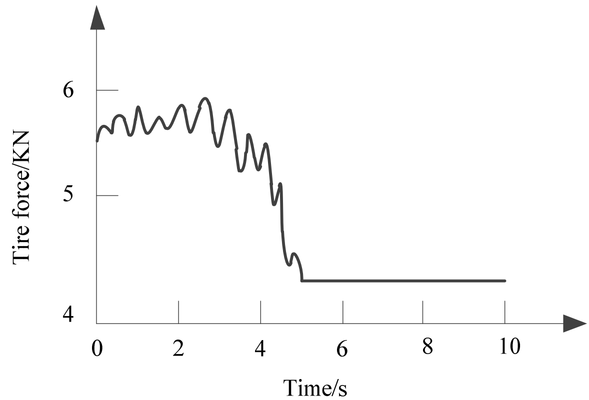


Figure 9 Curve of angle α with time

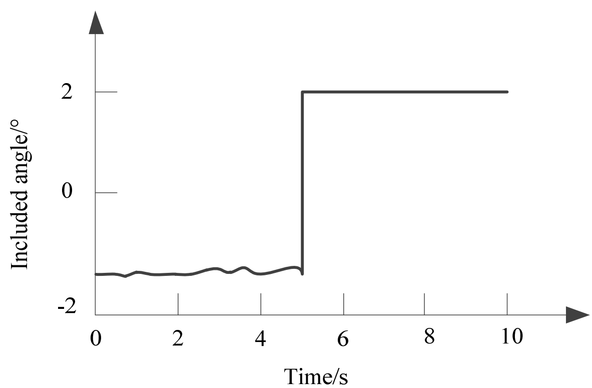
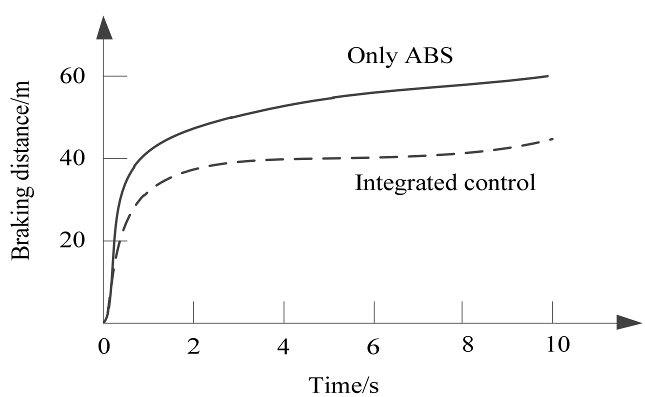


Figure 10 Braking distance curve



As can be seen from Figure 10, the braking distance of integrated control system is reduced by about 5 m compared with that of ABS only, and the braking time is also shortened by about 0.2 s. Therefore, the braking performance of integrated control system is better than that of ABS only system.

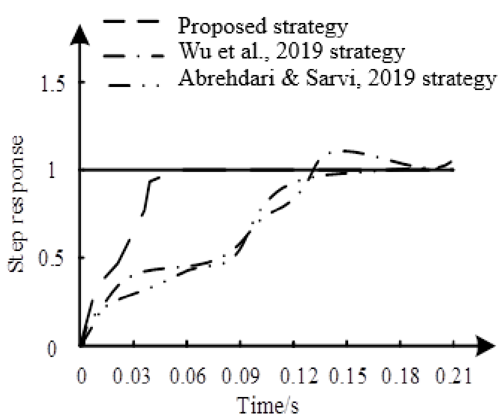
The comparison of vehicle performance is shown in Table 3.

Table 3 Comparison results of vehicle performance

Braking model	*Suspension model*	*Braking distance/m*	*Braking time/s*	*Maximum pitch angle/°*	*Maximum vertical acceleration*g*	*Pitch angle decay time/s*	*Decay time of vertical acceleration/s*
ABS	Passive Suspension	58	4.6	0.15	0.38	5.2	5.9
ABS	Active suspension	58	4.3	0.05	0.31	5.1	5.6

Figure 11 shows the step response of the research object under the control of different methods.

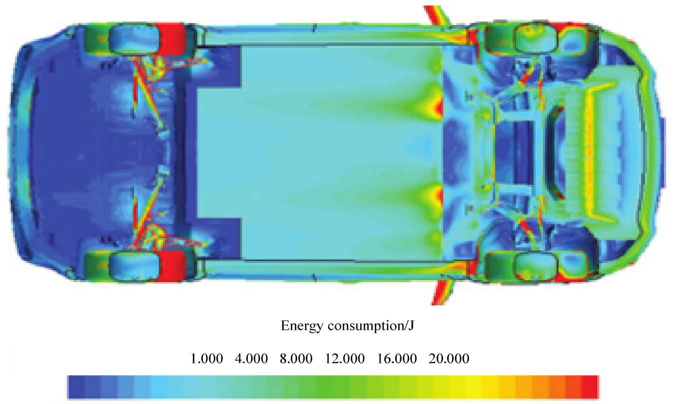
Figure 11 Step response of the method strategy presented in this paper



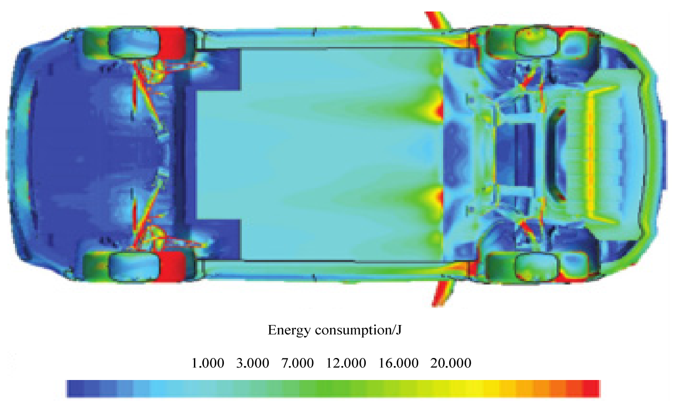
Analysis of Figure 11 shows that the time needed for the subject to enter the steady-state working state is about 0.12 s when Wu et al. (2019) strategy is adopted, and the phenomenon of overshoot occurs during the working process; The time needed for the subject to enter the steady-state working state is 0.12 s when Abrehdari and Sarvi (2019) strategy is adopted; The time needed for the subject to enter the steady-state working state from the beginning of the working process is about 0.05 to 0.06 s when the method is adopted to control the subject to work, and at the same time, there is no overshoot phenomenon during the subject's working process, which is beneficial to the subject’s communication work. Therefore, the response speed of the proposed method to control the steady state of the studied object is fast, and the steady state operation can be realised in a short time.

Energy consumption before and after vehicle integrated control is shown in Figure 12.

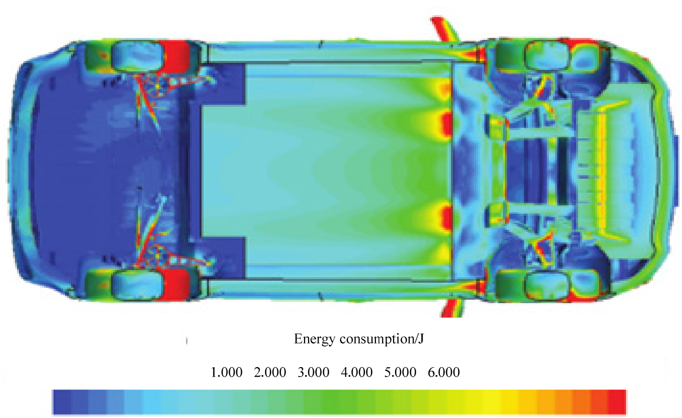
Figure12 Vehicle energy consumption under different strategies (a) Before optimisation (b) Vehicle energy after the application of the strategy in Abrehdari and Sarvi (2019) (c) The strategy in this paper is applied to automotive energy



(a)



(b)



(c)

Figure 12 provides a more intuitive analysis of the energy loss. The larger the area lost, the more energy is lost and the poorer the vehicle's kinetic energy. Figure 12 shows that both the traditional strategy and the proposed strategy can reduce the energy loss of the vehicle, but the energy loss area of the proposed strategy is obviously smaller than that of the traditional strategy, especially for suspension structure and battery pack. The proposed strategy shows obvious optimisation advantages, which can ensure the reduction of the energy consumption of the vehicle and improve the vehicle's dynamic performance.

4 Discussion

There are two major goals for the development of automotive chassis technology, namely, to improve safety and comfort. Under braking and downhill conditions, due to the recovery of vehicle kinetic energy or potential energy, the energy recovery system will exert additional force on the vehicle, and its effect will directly affect the vehicle's braking or driving performance. If the braking or driving control system fails to fully consider this additional force factor, the vehicle stability control will be disturbed and the vehicle will be unstable. The suspension system and anti-lock system play an important role in controlling the stability of the vehicle under braking and downhill conditions (Xin et al., 2018; Zhang et al., 2018). Therefore, how to control the suspension and ABS system and maintain the stability of the vehicle will be an urgent problem to be solved in the process of vehicle research. The solution of this research is to propose a parallel integrated vehicle control strategy based on the coordination of SAS and ABS. The relationship between energy recovery and stability control is studied by establishing the chassis parameter model. Based on the control parameters of battery, voltage and fuel consumption, an integrated control strategy for energy recovery and vehicle stability of parallel vehicles is designed.

The simulation test results show that when using the control strategy designed in this study, the time required for the subject to enter the steady state from the beginning of the working process is about 0.05 to 0.06 seconds and there is no overshoot phenomenon in the working process. However, when using the strategy shown in Wu et al. (2019) and (Abrehdari and Sarvi, 2019), the process takes 0.12 seconds, and overshoot phenomenon occurs. It shows that the braking performance of the control strategy designed this time is better, and the overall performance of the vehicle has been effectively improved. This result is also consistent with the research conclusion of Wen et al. (2019). From the perspective of energy conservation, both the traditional strategy and the proposed strategy can reduce the energy loss of vehicles, but the energy loss area of the proposed strategy is significantly smaller than that of the traditional strategy, especially for the suspension structure and battery pack, the energy loss area is significantly smaller than that of the traditional method. It can be seen that this strategy has obvious optimisation advantages, which can ensure the reduction of vehicle energy consumption and improve the dynamic performance of vehicles. He et al. (2019) also obtained similar research results.

5 Conclusion

Owing to the influence of parallel energy recovery process on vehicle stability control, the vehicle parallel integrated control strategy based on coordinated SAS and ABS is studied. The relationship between energy recovery and stability control is studied in order to optimise the vehicle energy consumption on the basis of stable driving. Based on the coordinated SAS and ABS, the integrated control of vehicle parallel connection is completed with the control parameters of vehicle battery, voltage and fuel consumption, and the overall performance is optimised. Experimental results show that the designed control strategy can effectively improve vehicle stability and reduce energy loss, which provides a reliable basis for the research in this field. However, due to the limited research conditions, this study failed to collect enough different kinds of data for experiments to fully verify the effectiveness of the design model, which is also the key point needed to be supplemented in future work.

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