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Modeling and Dynamics Analysis for Intelligent Skid-Steering Vehicle Based on Trucksim-Simulink

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***Abstract*—**Aiming at the verification of control algorithms for skid-steering vehicles, a vehicle simulation model of 6×6 electric skid-steering unmanned vehicle was established based on Trucksim and Simulink. The original transmission and steering mechanism of Trucksim are removed, and the electric skid-steering model and a closed-loop controller for the vehicle speed and yaw rate are built in Simulink. The simulation results are compared with the ones got by theoretical formulas. The results show that the predicted tire mechanics and vehicle kinematics of Trucksim-Simulink simulation model are closed to the theoretical results. Therefore, it can be used as an effective approach to study the dynamic performance and control algorithm of skid-steering vehicle. In this paper, a method of motion control based on feed forward control is also designed. The simulation results show that the feed forward control strategy can make the vehicle follow the target yaw rate more quickly and accurately, which makes the vehicle have more maneuverability.

***Keywords*—**Skid-steering, Trucksim-Simulink, feedforward control, dynamics.

I. Introduction

DIFFERENT from the common Ackermann steering vehicles, skid-steering vehicles do not rely on wheel steering, but change the direction by changing the speed of the two different sides wheels. Compared with vehicles that adopt geometric steering, skid-steering vehicles can achieve zero-radius steering, which improves steering performance. Wheels do not need to be deflected during steering, and related mechanisms can be omitted. Due to mobility and overall layout advantages, skid-steering vehicle is particularly suitable for off-road vehicles. At present, a variety of military or civilian wheeled vehicles at home and abroad have adopted differential steering programs [1]-[3].

In the research process of skid-steering vehicle dynamics control, simulation research is an effective way to reduce costs and improve efficiency [4], [5]. However, the study of the dynamics of skid-steering vehicles is still in initial stage. At present, skid-steering vehicle models are all built based on MATLAB/Simulink. The model has not been fully verified, the simulation conditions are set complicatedly, and it is necessary to establish a driver model by itself to complete closed-loop simulation [6]-[8].

Trucksim is a simulation software for dynamic simulation of vehicle dynamics. It uses feature-oriented parametric modeling. In this paper, based on Trucksim/Simulink, a skid-steering vehicle model is established, and the accuracy of the model is verified by comparison with theoretical calculation formulas. At the same time, a feedforward control method was designed. It greatly improves the stability and maneuverability of skid-steering vehicles [9]-[11].

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II. Trucksim/Simulink Co-Simulation Model

Trucksim is a mature simulation software, which is mostly used for vehicle dynamics simulation. It has features such as high degree of freedom, high simulation accuracy and stable operation. The user can freely set the vehicle model and simulation environment, and can display the motion process of the vehicle in a 3D animation. However, Trucksim does not have a skid-steering vehicle model; it needs to be co-simulated with Simulink. The electric drive system model and the controller model were established in Simulink. Several key methods were used to obtain the key dynamic parameters of the vehicle. A skid-steering vehicle simulation model was established.

A. The Vehicle Model in Trucksim

Trucksim is a mature commercial software, which has complete vehicle model and each system's model to choose. The user can modify the parameters of the existing model to complete the construction of the platform.

The model established in Trucksim is based on “spark” unmanned platform designed by Beijing Institute of Technology (Fig. 4). The platform uses two motors and transmits power to each side of the wheels by two conveyor belts. According to change the speed of the two motors, it changes the side wheel speed difference to achieve steering. Parts of the vehicle parameters are as follows.

TABLE I
VEHICLE PARAMETERS

vehicle parameters	value	Unit
Weight	300	kg
Drive mode	6×6	/
Steer mode	skid-steering	/
Tire radius	0.4015	m
1,2 Wheelbase	1836	mm
1,3 Wheelbase	3142	mm
Centroid to 1 axis distance	1650	mm
Total transmission ratio	28.26	/

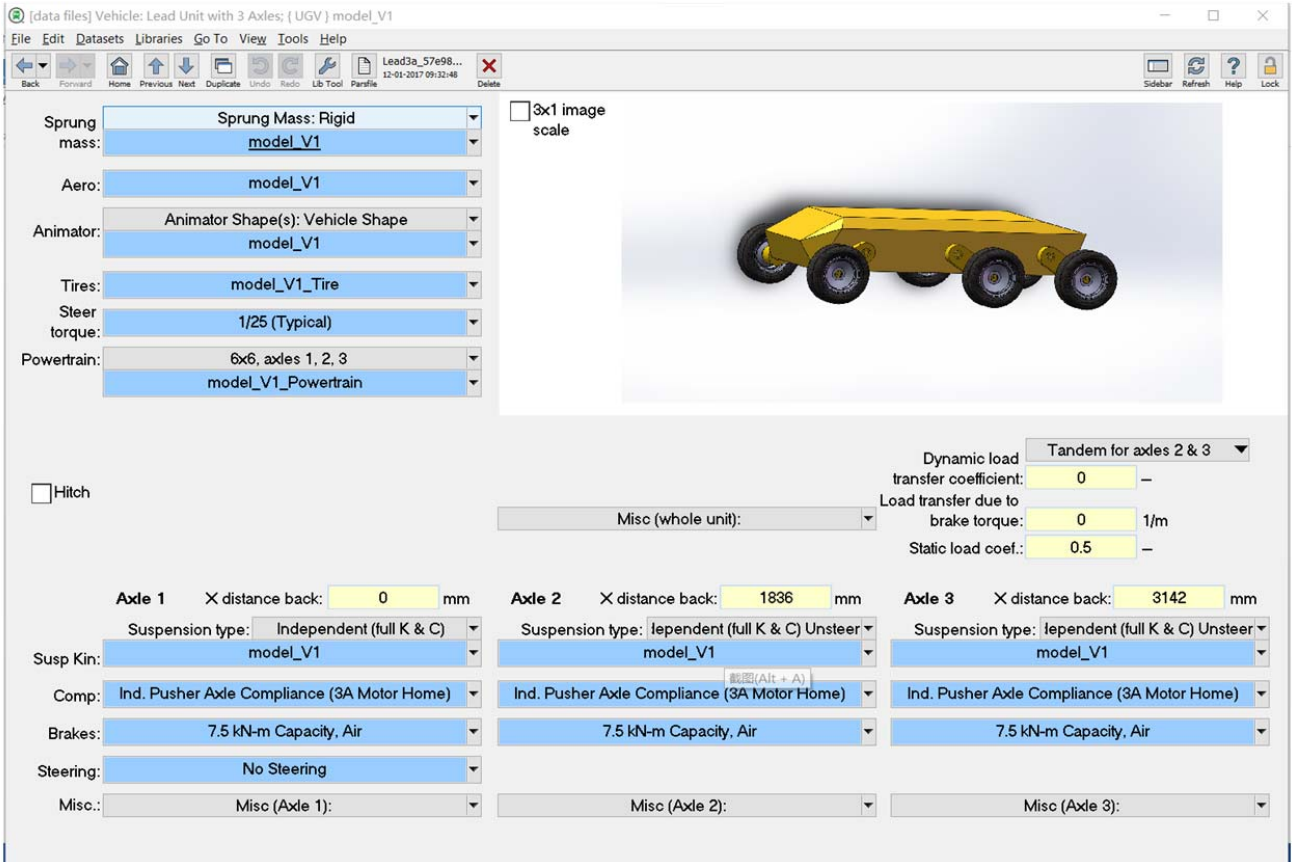

Fig. 1 Trucksim parameter setting

Fig. 2 “Spark” unmanned platform

Trucksim currently only has a complete simulation model for conventional vehicles; its power is transmitted from the engine to the wheels by the transmission. However, the power of this skid-steering test platform comes directly from the motor, so the transmission and steering system models cannot be used directly. In Trucksim software, the drive system is set as external input as shown in Fig. 3, and the steering system is set as No Steering.

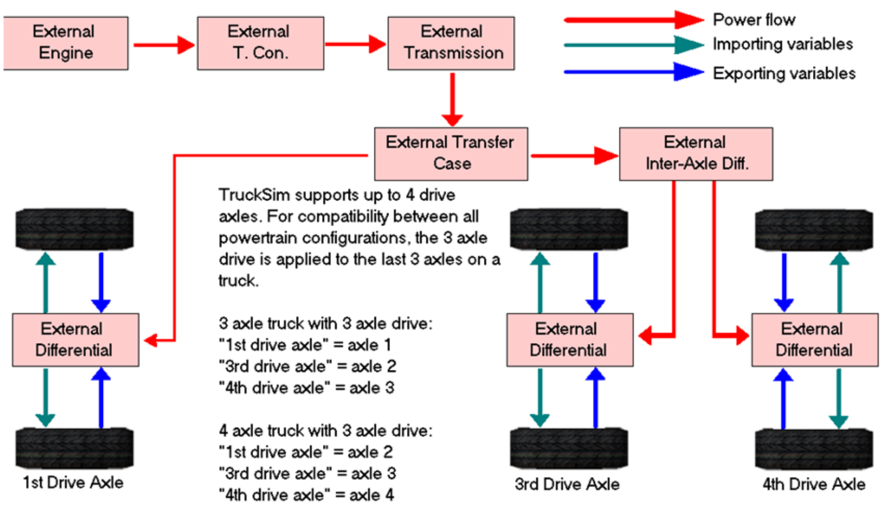

Fig. 3 Transmission settings

B. The Simulink Model

This article, through the co-simulation of Trucksim and Simulink, established a skid-steering vehicle model. Vehicle status information is obtained using the vehicle model in Trucksim and entered into Simulink. At the same time, in order to enable the vehicle to perform acceleration or deceleration and steering according to the intention of the driver, a vehicle controller and a motor model are established in Simulink to define the characteristics such as the speed and torque of the motor, and then the torque of the motor is directly loaded on the wheels. The co-simulation of Trucksim and Simulink can be done using the scheme shown in the figure.

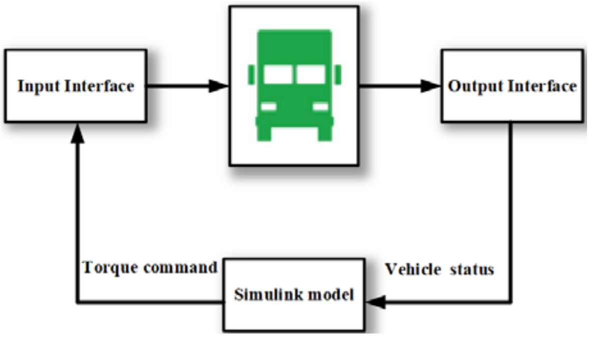

Fig. 4 Co-Simulation Block Diagram

Since the vehicle is actually motor driven, a motor model needs to be built in Simulink. The motor parameters are shown in Table II.

TABLE II
MOTOR PARAMETERS

Name	value	Unit
Peak power	75	KW
Peak torque	165	NM
Peak speed	14000	RPM

III. MODEL VALIDATION

In order to verify the accuracy of the model, the simulation conditions were designed to compare the theoretical calculation of the tire force and the Trucksim simulation output.

A. Simulation Condition

In order to compare the dynamic characteristics of the Trucksim model and the actual vehicle, the following experimental conditions were designed.

The vehicle runs at a constant speed of 3 km/h. A yaw rate step is applied in the 5 seconds, and the size is 10 deg/s, which remains unchanged. At this point the theoretical steering radius is 4.8 m.

B. Theoretical Model and Calculation Formula

Longitudinal force theory calculation formula:

$$Fx_1 = \frac{umgL}{4B} - \frac{fmg}{2}$$
$$Fx_2 = \frac{umgL}{4B} + \frac{fmg}{2} \quad (1)$$

In the formula, Fx is the tire longitudinal force, μ is the turning resistance coefficient, m is the whole vehicle mass, L is the vehicle length, B is the vehicle width, and f is the ground deformation resistance coefficient.

Vertical force theory calculation formula is:

$$Fz_1 = \frac{mg}{2} - \frac{H}{B} m(\dot{\upsilon} + u\omega_r)$$
$$Fz_2 = \frac{mg}{2} + \frac{H}{B} m(\dot{\upsilon} + u\omega_r) \quad (2)$$

In the formula, H is the height of the vehicle, $\dot{\upsilon}$ is the lateral acceleration of the vehicle, u is the longitudinal speed of the vehicle, and ω_r is the yaw rate of the vehicle.

C. Simulation Contrast

We compare the calculated results of the theoretical formula with the Trucksim output to verify the accuracy of the model.

1. Comparison of the longitudinal force of the wheel when steering

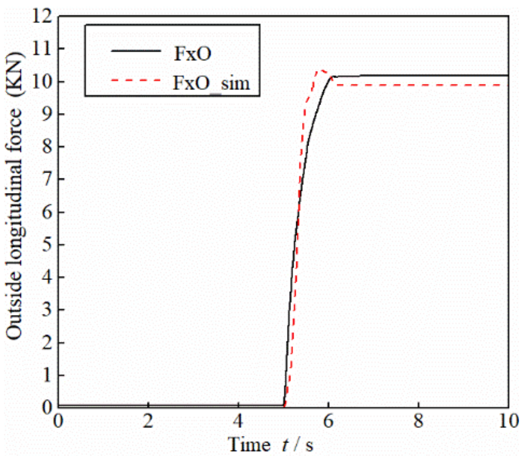

Fig. 5 Outside wheel longitudinal force

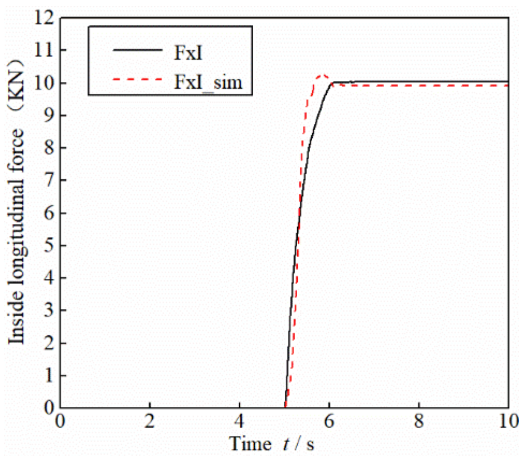

Fig. 6 Inside wheel longitudinal force

2. Comparison of the vertical force of the wheel when steering

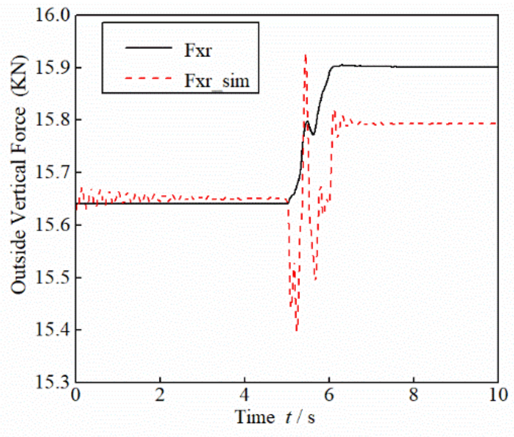

Fig. 7 Outside wheel vertical force

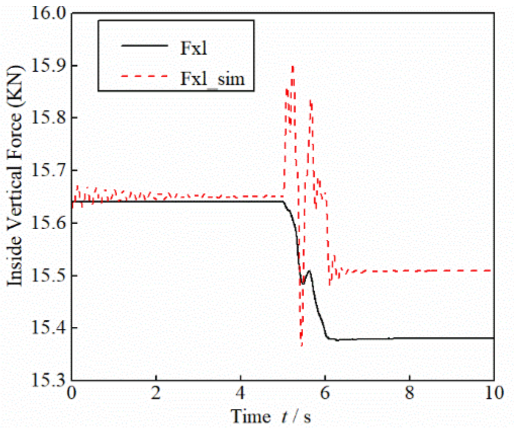

Fig. 8 Inside wheel vertical force

The results show that, under typical conditions, the longitudinal and vertical forces of Trucksim vehicle model tires are consistent with the theoretical calculation formula, which can prove that the Trucksim model established in this paper is accurate and reliable.

IV. Feedforward Control Method

The actual vehicle experiment shows that the traditional PID control method is more difficult to make the true yaw rate of the vehicle accurately follow the target value. Therefore, this paper designs a control method based on torque feedforward and validates it with Trucksim/Simulink model.

A. Feedforward Control Method Design

Due to the absence of traditional steering mechanisms, skid-steering vehicles are subject to greater steering resistance during steering. This paper calculates the longitudinal force required for steering based on the longitudinal force calculation formula for the steering of the speed difference and the target speed and yaw rate when the vehicle is turning. The feedforward control is added to the steering control system. The block diagram of the control method is as follows.

The PID controller parameters are shown in Table III.

TABLE III
PID Controller Parameters

Name	value
Kp	120
Ki	10
Kd	0

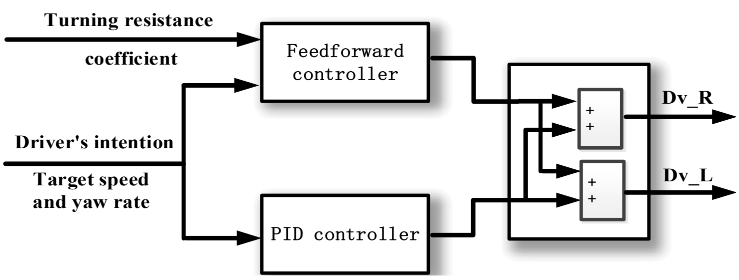

Fig. 9 Feedforward Control

B. Comparison of Different Control Methods

To verify the performance of the feedforward control method, two operating conditions were designed, and the result was compared with the direct PID control method.

Condition 1.The vehicle runs at a constant speed of 10 km/h. Give a yaw rate step in the 5th second, with a size of 20 deg/s, which remains unchanged.

Condition 2.The vehicle runs at a constant speed of 30 km/h. Give a yaw rate step in the 5th second, with a size of 20 deg/s, which remains unchanged.

We simulate the two conditions separately and get the following results:

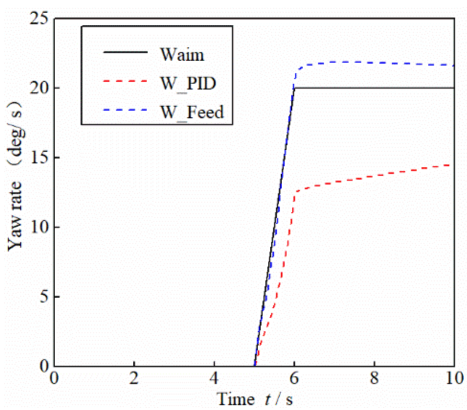

Fig. 10 Condition 1

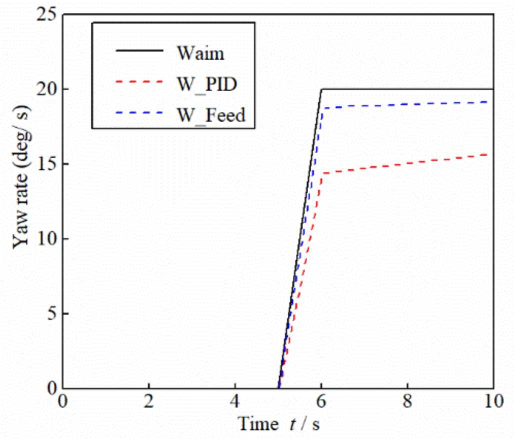

Fig. 11 Condition 2

The results show that the feedforward control based on the longitudinal force is prone to overshoot at low speed. However, with the speed increases and the turning radius decreases, the overshoot phenomenon disappears. Compared with the PID control method, the feedforward control method can make the vehicle more quickly and accurately follow the target yaw rate, so that the vehicle steering response capability is faster and the mobility is enhanced.

V. Conclusion

This paper establishes a 6×6 skid-steering vehicle model based on Trucksim/Simulink co-simulation. These include the setting of vehicle parameters in Trucksim and the setting of the co-simulation interface. In addition, a skid-steering vehicle motion controller was established in Simulink, and simulation conditions were set.

Through the simulation of the steering conditions, the tire forces obtained from the joint simulation model and the theoretical formula are compared to verify the accuracy of the model.

A feedforward control method was designed and compared with traditional PID control method through high and low speed operating conditions. It is verified that the feed forward control method has fast and accurate follow ability and strong stability, which can greatly improve the maneuverability of the vehicle.

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