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• Supplementary File •

Longitudinal-vertical integrated controller based on sliding mode controller for distributed electric vehicle

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Appendix A The parameters of the sliding mode motion controller.

The sliding mode controller has strong anti-interference ability. Even if there is internal disturbance or external disturbance of the system, the system can maintain a stable state. In this paper, the parameter table of the SMC is obtained in Table A1 under the co-simulation of MATLAB and CarSim.

Table A1 The parameters of the SMC

parameter	value	parameter	value
η_{1n}	10	q_3	13
ϕ_1	0.1	p_3	15
η_{2n}	10	α_{3n}	120
ϕ_2	0.1	β_{3n}	10
α_3	1	q_{3n}	9
β_3	1	p_{3n}	13

Appendix B Simulation and analysis

The simulation of MATLAB/simulink and CarSim software is used to verify the longitudinal-vertical force control of four-wheel-drive electric vehicles. The vehicle model used in CarSim is a type A car. The vehicle model geometry parameters defined in CarSim are shown in Table B1.

Table B1 Four-wheel drive electric vehicle model parameter

parameter	value	unit
m_s	830	kg
l_f	1.103	m
l_r	1.244	m
r	0.297	m
I_x	288	$kg \cdot m^2$
I_y	1110.9	$kg \cdot m^2$
I_z	1110.9	$kg \cdot m^2$
$T_{i,max}$	250	Nm

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Appendix B.1 Variable acceleration linear condition

The initial velocity is $36km/h$ and the acceleration is shown in Figure B1. It is to verify the stability of the controller under high-speed conditions. As can be seen from Figure B1, the vehicle has an acceleration of 0 in 0-1 s. The vehicle gradually accelerates in 1-2 s until the acceleration is 3.5 m/s^2. The acceleration of the vehicle continues to increase to 7 m/s^2 in 2-4 s and maintains for 1 seconds. In 5-7 s, the acceleration gradually reduces to 0.

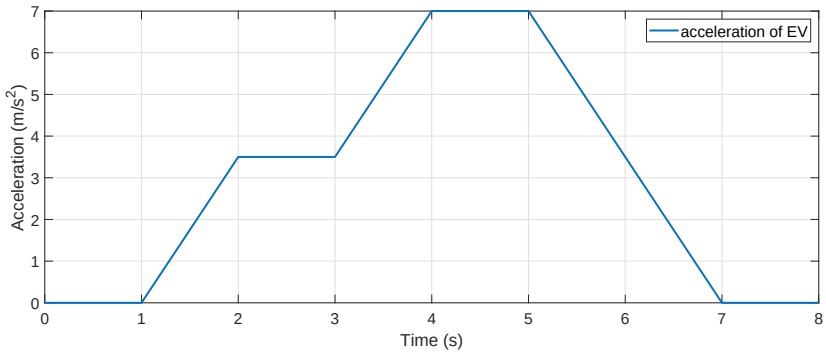

Figure B1 The acceleration of EV

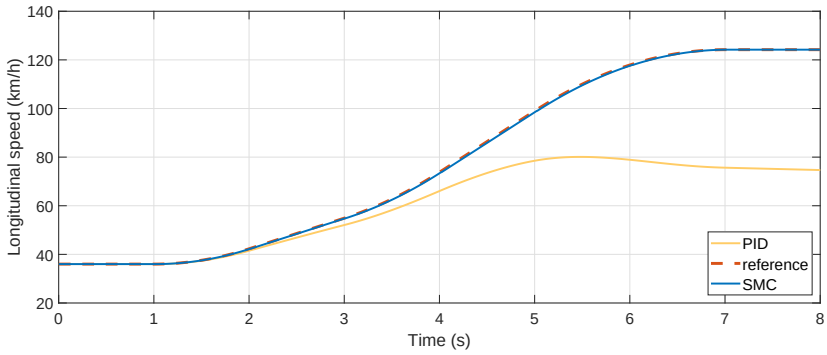

Figure B2 The longitudinal speed of EV

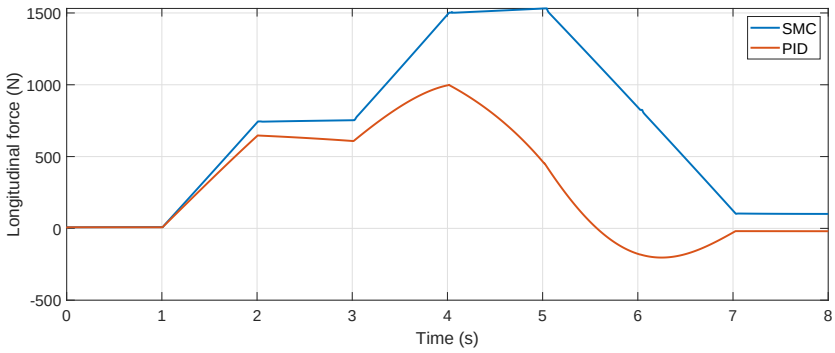

Figure B3 The longitudinal force of EV

Vehicle desired speed is 36 km/h uniform speed during 0-1 s, accelerates to 124.2 km/h in 1-7 s and maintains to 8 s. From the Figure B2, the vehicle is accelerate to $124.19km/h$ at $7s$ and maintains it by SMC. However,the vehicle is accelerate to 80.09 km/h at $5.5s$ and gradually reduce and finally stabilize to 74.68 km/h by PID. Speed tracking error is 0.008% for SMC and 39% for PID.

Combined with the longitudinal force in Figure B3, driving force is provided to ensure the acceleration performance of the vehicle for SMC control, but there is still chattering when the acceleration changes. For PID controller, after 4 s, the

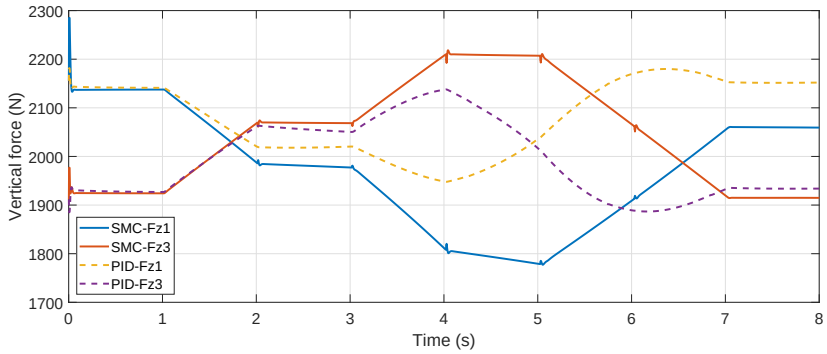

Figure B4 The vertical force of EV

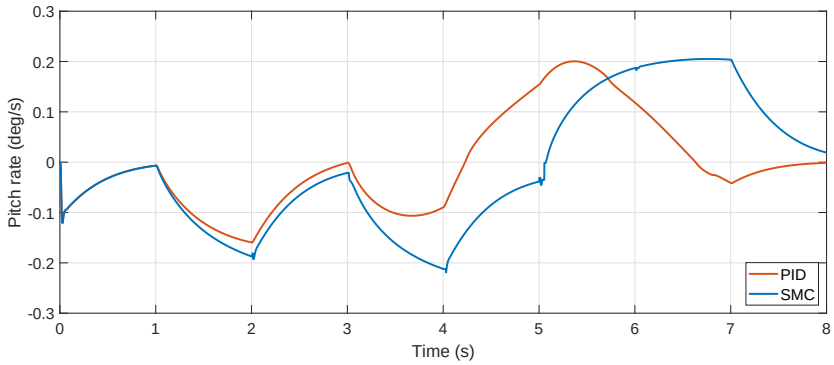

Figure B5 The pitch rate of EV

longitudinal force suddenly decreases. After 5.5 s, the longitudinal force is reduced to a negative value causing the vehicle to decelerate. It does not provide enough driving force to achieve speed tracking of the vehicle.

In the Figure B4, the vertical force is shown. Since the longitudinal force is not tracked in the PID control, the vertical force change trend is also different from the SMC control. During 2-3 s, the force of the left front wheel is 1984 N and the force of the left rear wheel is 2069 N for SMC. PID controller cannot track vertical force after 2 s.

The pitch rate is also varies between -0.2 to 0.2 deg/s shown in Figure B5. For SMC, the vehicle acceleration becomes larger, the pitch rate gradually increases between 1-2 s. In 2-3 s, the vehicle maintains a constant acceleration, so the pitch rate gradually approaches 0. After 5 s, since the vehicle acceleration decreases, the pitch rate becomes positive and becomes larger.

Comparing the PID with the SMC, it can be seen that although the vehicle performance is similar at low speed, the PID controller loses stability at high speed. The effect of SMC motion controller is verified.