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Combined control methods of the steering and traction system of in-wheel electric vehicle for a double lane-change in a low friction coefficient environment

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Abstract. This paper proposed advanced design strategy of adaptive controller for steering and traction control system of in-wheel EV is proposed. Proposed algorithm is highly recommended for the first step driver to drive car under unstructured environment. When people drive a car on low friction coefficient road such as snowy or icy road, slip could be happen which disturb safe driving.
This paper proposed stable driving algorithm when driving on snowy or icy road.
Proposed algorithm has been verified and demonstrated through the co-simulation between Carsim and Matlab.

Key words
EV(electric vehicle), double lane-change, steering system, traction control system, slip

1. Introduction

The latest technologies of electric vehicles can be divided into two parts, safety and environment.
As a result of these up-coming trends, eco-technology and stability of automotive industry has been absolutely technology.
And various kinds of electronic control devices and technology are concentrated on hybrid electric vehicle(HEV) and fuel cell electric vehicle(FCEV) in order to prevent unexpected accidents caused by the negligence of the driver.
Recently, active safety and Advanced Driver Assistance Systems (ADAS) technology has been raised to core-technology.[1]
The in-wheel motors for electric cars have been actively researched for simultaneously satisfy these eco-friendly and high vehicle stability system.
Therefore, this paper proposes efficient and reliable vehicle safety algorithm with steering control *w.r.t.* lateral direction and traction control *w.r.t.* longitudinal direction.

2. Vehicle model

A. The motor

Proposed in-wheel vehicle system is operated by two IPMSM motors with double layer concentrated winding which are specially designed at KERI, and stated IPMSM motor is illustrated in Fig. 1.

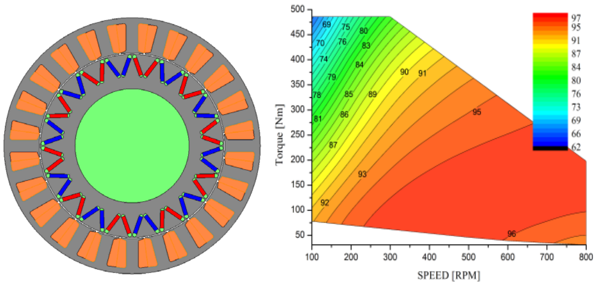


Fig.1 Designed IPM motor and its efficiency map

The main specifications of the motor are given in Fig.2.

SPECIFICATIONS OF STUDIED MOTOR

Parameter	
Poles / Slots	20 / 24
Output power(peak)	15 kW
Base speed	300 rpm
Max torque	480 Nm
Stator outer diameter	270 mm
Stator inner diameter	194 mm
Stack length	120 mm
Air gap length	1 mm
Rated current density	5 A/mm^2
Remanence flux density of PM	1.1 T

Fig.2 The main specifications of the motor

B. Target Vehicle Model

In-wheel EV is operated by two rear wheels, which contains IPM motors. In order to simplify the vehicle structure, generally used bicycle model has been adopted.

Detailed description of bicycle model is stated in Fig.3. [2].

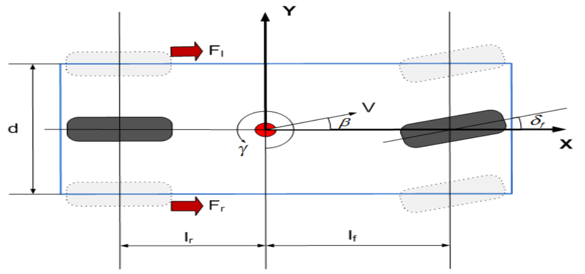


Fig.3 Bicycle model with two degrees of freedom

Here, F_l, F_r, γ, δ_f, d and β are the force of rear left tire, the force of rear right tire, the yaw-rate, the steering angle, the distance between left wheel and right wheel and the sideslip angle**,** respectively.

C. Yaw-rate control for steering

Yaw rate control carries out posture control of in-wheel EV during cornering condition with longitudinal velocity and steering angle information.
In order to prevent over steer and under steer condition like Fig. 4, slip control *w.r.t.* lateral direction, *i,e* yaw rate control should be executed in real time.
The blue arrow is yaw-rate for safely control a vehicle.

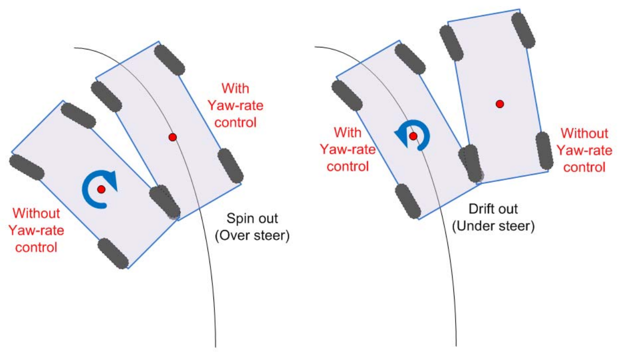


Fig.4 Yaw rate control for over steer and under steer

Desired yaw rate and steering angle is,

$$\gamma_{des} = \frac{V}{l_f + l_r + \frac{mV^2(l_r C_{ar} - l_f C_{af})}{2C_{ar}C_{af}(l_r + l_f)}} \tag{1}$$

$$\delta_{fs} = \frac{1}{k}\,\delta_{hs} \tag{2}$$

where, γ_{des} , V , m , l_f, l_r, C_{af} , C_{ar} , δ_{fs} , δ_{hs} and k are the desired yaw-rate, vehicle speed, vehicle mass, distance between C.O.G and front wheel, the distance between C.O.G and rear wheel, the cornering stiffness of front tire, the cornering stiffness of rear tire, the steering angle of front wheel, steering angle of handle and gear ratio for steering ,respectively[3].

D. Traction control for safety

T_{com} is the torque command to motor. ω is the rotational speed of the car tire. Vehicle slip λ is defined as the ratio between vehicle speed and wheel speed.
The vehicle body can be seen one real inertia system.

$$J_{real} = J_\omega + Mr^2(1 - \lambda) \tag{3}$$

If we use the following inertia moment with $\lambda = 0$ in the reference model,

$$J_{ideal} = J_\omega + Mr^2 \tag{4}$$

Without slip, J_{real} is exactly equal to J_{ideal}.
Where, J_{real} , J_{ideal} and J_ω are Equivalent inertia moment, The ideal inertia moment, The shaft inertia moment, respectively[4].

3. Proposed method

A combination of the two methods, yaw rate control and traction control, can make following equation.

$$I_{com} = T_{com} * K_{com} \tag{5}$$

$$I_{com} * FD = F_{trac} \tag{6}$$

And,

$$\gamma_{des} - \gamma_{real} = \gamma_{steer} \tag{8}$$

$$\gamma_{steer} * K_{steer} = M_{steer} \tag{9}$$

Where, I_{com}, T_{com}, K_{com}, FD, F_{trac}, γ_{des}, γ_{real}, γ_{steer}, K_{steer} and M_{steer} are command current, command torque, command current gain, generated force, traction force, desired yaw-rate, the real yaw-rate, the yaw-rate for steering and desired yaw-moment for steering.
Each motor torque is

$$TRL = r\left(\frac{F_{trac}}{2} - \frac{M_{steer}}{t}\right) \tag{10}$$

$$TRR = r\left(\frac{M_{steer}}{t} + \frac{F_{trac}}{2}\right) \tag{11}$$

where, F_{trac}, M_{steer}, TRL, TRR, t and r are longitudinal traction force, steering inertia moment, torque for rear left wheel, torque for rear right wheel, half the distance between left wheel and right wheel and radius of wheel.

Fig. 5 illustrates overall scheme of proposed algorithm, which is combined with yaw rate control and traction control as stated in introduction in order to improve vehicle stability.

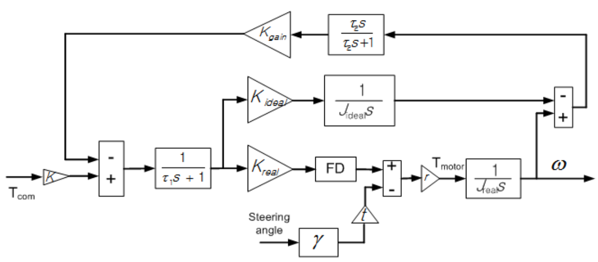


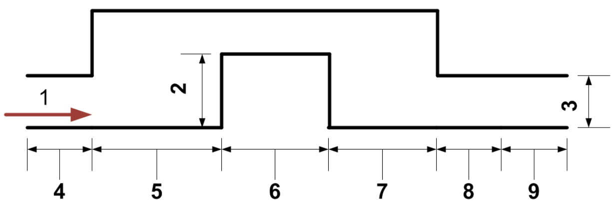
Fig.5 Block diagram of proposed overall algorithm

4. Simulation results

A. Simulation

In order to demonstrate proposed algorithm, the collaboration between Carsim and Matlab has been utilized.
As input parameters to this simulation is:

1) The input torque is 80N.m
2) The friction coefficient is 0.85 and 0.3
3) The steering is Double Lane-Change. The test load for simulation is as Fig 6 and Fig7.



1. Direction of driving	4. Section 1	7. Section 4
2. Offset of Lane	5. Section 2	8. Section 5
3. width	6. Section 3	9. Section 6

Fig. 6. The test load for simulation

Section	Length	Offset of Lane	Width
1	15		1.1 * L + 0.25
2	30		
3	25	3.5	1.2 * L + 0.25
4	25		
5	15		1.3 * L + 0.25
6	15		1.3 * L + 0.25

Fig. 7. The length and width of a section. Where, L = Overall width of Vehicle

The simulation result are Fig .6, Fig .7, Fig .8 and Fig. 9.

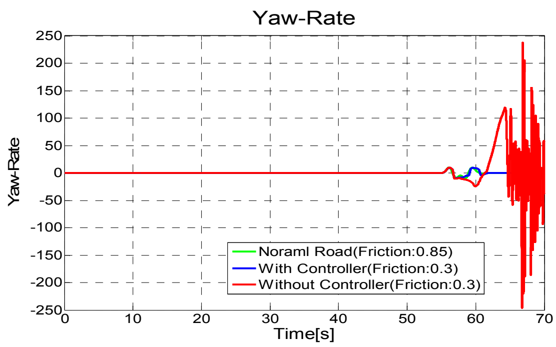


Fig. 8. Simulation result of yaw -rate under Double Lane-Change

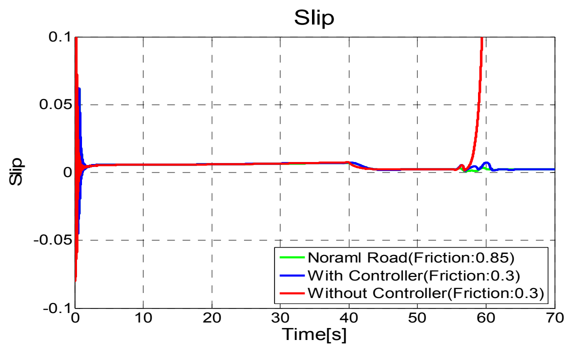


Fig. 9. Simulation result of slip under Double Lane-Change

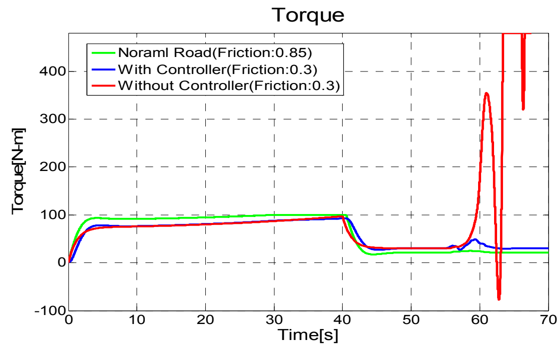


Fig. 10. Simulation result of torque under Double Lane-Change

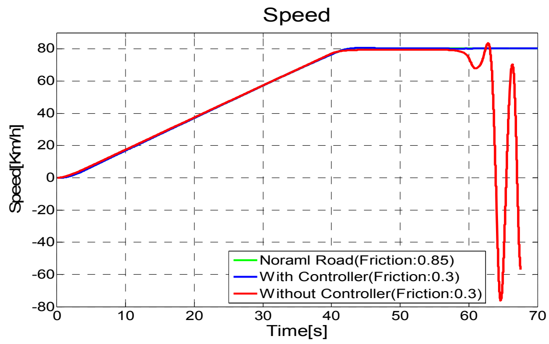


Fig. 11. Simulation result of vehicle speed under Double Lane-Change

Figure.8 illustrates vehicle's yaw rate under Double Lane-Change. Without controller, yaw rate of in-wheel vehicle finally oscillation, on the other hand, The 'With controller' model can converge within pre-fixed bounded value.
Figure.9 shows slip ratio of in-wheel EV. Around 55 seconds after, slip ratio also diverges to infinite under 'without controller' case.
Fig.10 shows wheel torque. The motor torque is also diverges to infinite like "slip under Double Lane-Change" case. However, when using the proposed method, the torque to motor is controlled depending on the steering and slip that does not oscillate.
Fig.11 shows the vehicle speed. Maximum vehicle speed cannot exceed 80km/h. we cannot control a vehicle under 'without controller' case. on the other hand, vehicle is well controlled under 'with controller' case.

5. Conclusion

This paper proposed advanced posture control algorithm of in-wheel EV using cooperation between yaw rate control and traction control, *w.r.t.* lateral and longitudinal direction, respectively. As most representative characteristics, relatively fast torque response and exact wheel torque estimation is superior to conventional power train system, which based on internal combustion engine. this paper was applied "steering control method" to secure the steering stability and "Traction control method" to secure the longitudinal force stability under the low friction coefficient environment such as icy road or snowy road. The performance of the control algorithm was verified by performing co-simulation using the CARSIM and MATLAB.

References

[1] Minseok Choi, Changjun Kim, Dongyung Kim, Sangho Kim and Jooyoung Choi, "A Study on Improving Stability of In-wheel motored FR Electric Vehicle in Cornering using Independent Drive Control", KSAE2011, Division General Conference, 2011.5, 1142-1146

[2] Kanghyun Nam, Sehoon Oh and Yoichi Hori, "Robust Yaw Stability Control for Electric Vehicles Based on Active Steering Control", Vehicle Power and Propulsion Conference (VPPC), 2010 IEEE , pp. 1-5.

[3] Hiroshi Fujimoto, Take0 Saito, Akio Tsumasaka and Toshihiko Noguchi, "Motion Control and Road Condition Estimation of Electric Vehicles with Two In-wheel Motors", IEEE2004, International Conference on Control Applications, pp. 1266 - 1271 Vol.2

[4] Yoichi Hori, *Member, IEEE*, Yasushi Toyoda, and Yoshimasa Tsuruoka, "Traction Control of Electric Vehicle: Basic Experimental Results Using the Test EV "UOT Electric March" ", IEEE1998, TRANSACTIONS ON INDUSTRY APPLICATIONS, VOL. 34, NO. 5, SEPTEMBER/OCTOBER 1998, pp. 1131-1138.