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Advanced VDC simulations of In-wheel electric vehicle using Carsim and Simulink

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Abstract

Conventional engine based vehicles inevitably have complicated structures due to lots of elements. Because of this characteristic, research, development, and also marketing are mainly conducted by the conglomerate, like GM, BMW, Honda, and Hyundai motors, etc. But environmental pollution and fuel exhaustion by the stated vehicle increase the necessity of EV(Electric Vehicle) as a representative of green car. First of all, the structure of EV is relatively simple, and energy transmission ratio of electric motor is more efficient than the engine based power train system. In addition to these, inwheel EV can estimate exact wheel torque, which is the most fundamental information for slip control, such as VDC(Vehicle dynamics control)/TCS(Traction control system)/ABS(Anti-lock brake system). Various kinds of expectable situations during EV's navigation have been simulated through the coordination between 'Carsim' and 'Simulink'.

Keywords: In-wheel EV, Direct torque control, VDC(Vehicle dynamics control), slip control

1 Introduction

Recently, most of car-manufacturers have concentrated on EV by the social needs to the green vehicles. First of all, EV can significantly decrease fuel consumption which causes serious environmental problems. In addition to this, EV is expected to realize demand oriented production system because of its relatively simple structure. Direct torque transmission structured EVs consist of in-wheel type and in-axis type. Both kinds of structures have their own pros and cons, such as in-wheel EV could be controlled wheel by wheel, so this structure guarantees high stability, smooth cornering and ABS-like system through optimal torque distribution to each wheel. But it's vulnerable for external disturbances and impulsive shock which contains high frequency, and it requires precise speed control for straight driving. In this paper, various kinds of expectable situations during the EV's navigation have been simulated through the collaboration between 'Carsim' and 'Simulink'.

Carsim's fundamental features are highly focused at conventional power-train system, engine torque converter-transmission-differential gear-wheel. In order to simulate in-wheel EV, make practical motor modeling in Simulink, and insert it into the in-wheel EV′s power train instead of engine in the conventional power train system. Detailed simulation environment is shown at figure 2 in section 2. This paper consists of four sections, including introduction. Section 2 describe proposed VDC algorithm of in-wheel EV and important simulation environments, section 3 illustrates simulation results for most representative four cases, section 4 finally concludes and presents some future works.

2 VDC algorithm of in-wheel EV

2.1 Conventional In-wheel EV researches

In-wheel EV is mainly researched by the traditional motor manufacturer, especially Protean[1], Michelin[2], AISIN[3], NTN[4], etc.

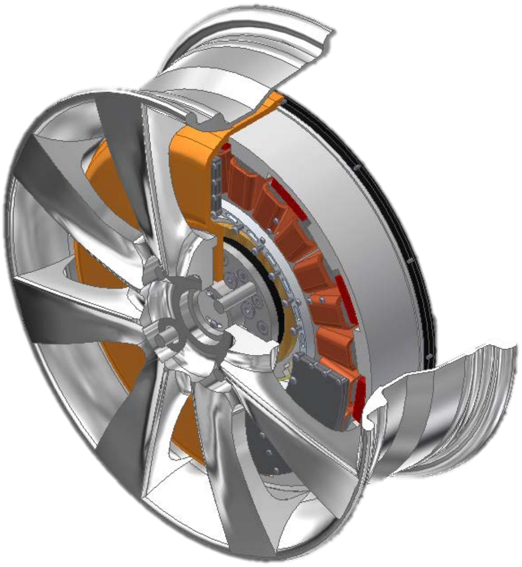

Figure 1 : Newly developed KERI's in-wheel motor

The most significant technologies for the in-wheel EV is high torque density and robustness against external disturbances, and precise speed/torque control ability. Traditionally, the ratio between sprung mass and un-sprung mass affects vehicle's stability and driving comfort, so heavy weighted wheels diminish these two important vehicle characteristics. Robustness against external disturbances is directly related to maintenance problems and the life cycle of vehicle. Slip control of in-wheel EV is mainly conducted by Hori lab, the university of Tokyo[5]. Hori lab realized TCS by applying MFC(Model Following Control) in 2001[6], and recently proposed MTTE(Maximum transmissible torque estimation)[7] to enhance robustness as well as reliability.

2.2 Proposed VDC algorithm for in-wheel EV

Figure 2. illustrates overall block diagram of proposed VDC algorithm.

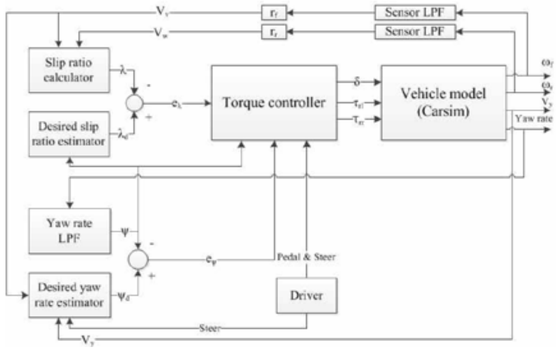

Figure 2 : Proposed VDC algorithm for in-wheel EV

Torque controller calculates wheel torque based on error of slip ratio, yaw rate, and driver's accelerator pedal information. Vehicle model is replaced by Carsim block, slip ratio calculator attains forward wheel speed as estimator for vehicle speed, and rear wheel speed. The ratio between vehicle speed and wheel speed is defined as vehicle's slip ratio, and difference between desired slip ratio and estimated vehicle's slip ratio is controller input along vehicle's longitudinal axis. On the other hand, the between desired yaw rate and vehicle's yaw rate is another controller input along lateral axis. Detailed derivation of desired slip ratio and yaw rate is described in section 2.2.1 and 2.2.2, respectively.

2.2.1. Desired slip ratio

Fixed value, generally between 0.15~0.2, is widely utilized in the former researches[8]. Figure 3. illustrates relationship between friction coefficient, mu, and vehicle's slip ratio, lambda by Pacejka's magic formula[9]. Most of the cases, except for cobblestone environment, road's adhesion coefficient is maximized when vehicle's slip ratio is around 0.15. So, conventional researches set desired slip ratio as fixed value, 0.15. But vehicle's adhesion coefficient is varying by the vehicle's rotation elements. In this paper, desired varying slip ratio is determined as,

$$\lambda_d = \lambda_{default} - 0.05\left|\frac{\dot{\psi}}{\dot{\psi}_{\max}}\right| = 0.15 - 0.05 \cdot \left|\frac{\dot{\psi}}{\dot{\psi}_{\max}}\right| \quad (1)$$

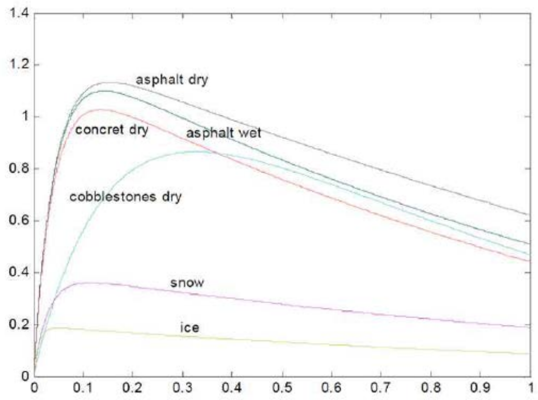

Figure 3 : Tire's mu-lambda curve

In default slip ratio is set as 0.15 as usual, and proposed desired slip ratio is varying according to the vehicle's normalized yaw rate as rotational information. Maximum yaw rate is tentatively selected as 100 rad/s by heuristic method, which is maximum yaw rate during slalom driving.

2.2.2. Desired yaw rate

By the vehicle's lateral dynamics in [10], yaw rate is stated as,

$$\dot{\psi} = \frac{V_x\{\tan(\delta_f) - \tan(\delta_r)\}\cos(\beta)}{l_f + l_r} \quad (2)$$

Where is V_x is vehicle speed, δ_f and δ_r are front and rear wheel's steering angle, β is vehicle slip, and finally l_f and l_r are distance between front wheel to COM and rear wheel to COM, respectively. Also from [10], vehicle's slip angle is derived as,

$$\beta = \tan^{-1}\left[\frac{l_r \tan(\delta_f)}{l_r + l_f}\right] \quad (3)$$

In order to derive vehicle's desired yaw rate, (3) is substituted into (2). So we can attain vehicle desired yaw rate as in (4), which is a function of steering angle, vehicle's longitudinal and lateral speed when vehicle's COM is fixed.

$$\dot{\psi}_d = \frac{V_x \tan(\delta_f)\cos(\tan^{-1}(\frac{V_y}{V_x}))}{l_f + l_r} \quad (4)$$

2.2.3. Wheel torque calculation algorithm

In this paper, proposed wheel torque is calculated with the driver's accelerator pedal information, slip ratio error, and yaw rate error. Its detailed numerical formula is defined as,

$$\tau_{rl} = T(P) \cdot \{1 - (1-k)\frac{e_\lambda}{e_{\lambda\max}}\}\{1 - k\frac{e_{\dot{\psi}}}{e_{\dot{\psi}\max}}\} \quad (5)$$

$$\tau_{rr} = T(P) \cdot \{1 - (1-k)\frac{e_\lambda}{e_{\lambda\max}}\}\{1 + k\frac{e_{\dot{\psi}}}{e_{\dot{\psi}\max}}\} \quad (6)$$

Where T(P) is driver's accelerator pedal, e_λ is slip ratio error, $e_{\dot{\psi}}$ is yaw rate error, k is vehicle's rotational factor defined as,

$$k = \left|\frac{\dot{\psi}}{\dot{\psi}_{\max}}\right| \quad (7)$$

3 Simulation

3.1 Simulation environment

As mentioned in introduction, carsim's default interface is established on engine based powertrain system. So we have to make a suitable motor model to simulate inwheel EV as fig. 4. shows carsim's internal setting so as tso in-wheel EV simulation and its fundamental simulation scheme. T-N curve(Rpm-torque curve) is designed using user defined function, which is torque command input of motor to Carsim. Other parameters, like tire radius/ friction constant/ overall length/ weight/ slanted angle of road is set in the Carsim as shown in table 1.

Table 1. Some important internal Carsim parameters

Category	Value	Unit
Front wheel-COM	1103	mm
Front wheel-Rear wheel	2347	mm
Vehicle mass	747	kg
Slanted angle	0	deg
Tire radius	292	mm
Road friction coefficient	0.85	-

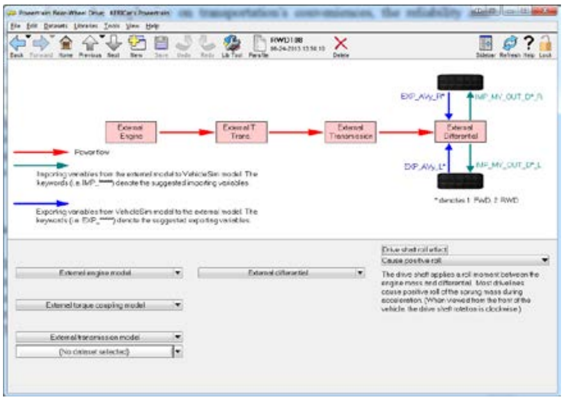

Figure 4 : Internal setting of Carsim for in-wheel EV and fundamental simulation scheme

We propose five most representative environments to simulate in-wheel EV, which is split mu braking test(ISO14512), double lane change(ISO3888), slalom(S-turn), Circle, and J-turn. Our proposed VDC algorithm has been demonstrated under stated five environments by comparing slip ratio, lambda, slip angle, beta, tire's longitudinal and lateral force, and yaw rate, *etc.*

3.2 Simulation result

This section describes simulation results for stated environment. Each figure has its own short caption for most distinctive features.

3.2.1. Double lane change(ISO3888)

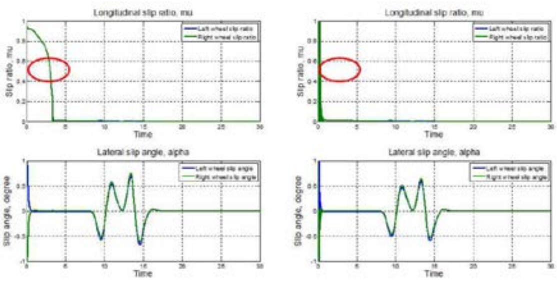

Figure 5 : Slip ratio and slip angle of without VDC/with VDC for double lane change

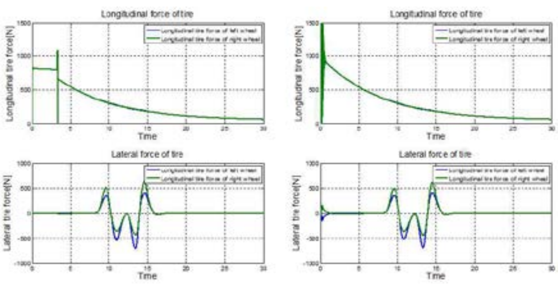

Figure 6 : Tire's longitudinal/lateral force of without VDC/with VDC

3.2.2. Slalom(S-turn)

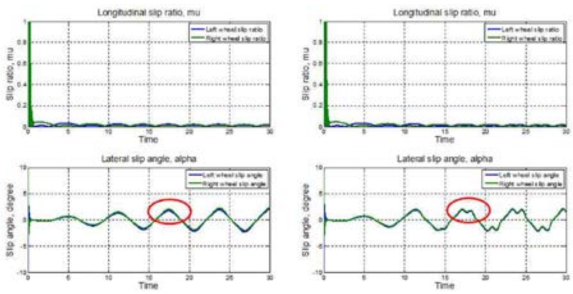

Figure 7 : Slip ratio and slip angle of without VDC/with VDC

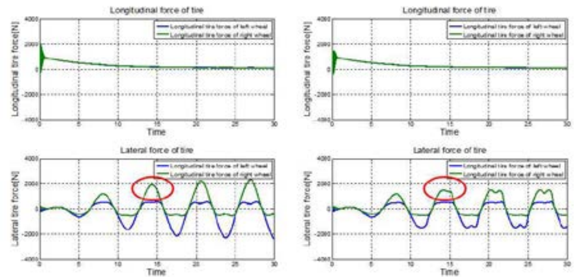

Figure 8 : Tire's longitudinal/lateral force of without VDC/with VDC

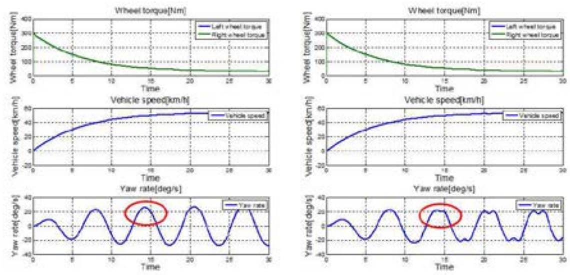

Figure 9 : Wheel torque, vehicle speed, and yaw rate for slalom simulation

4 Conclusions

Most EV experts have consentaneously announced that the most significant bottleneck of EV is battery problem. Its low energy density, short driving distance per full charging state, insufficient life cycle, and heavy weight are slowing EV down not to be next generation's transportation. But EV is an inevitable and huge wave heads for our future. As emphasize on transportation's conveniences, the reliability and stability issues should be considered concurrently. Moreover, in-wheel EV might be a good and the only solution for specialized EV fields, such as personal mobility system with distinctive chassis. This paper suggests in-wheel EV's prospective forecasts, and stability problems. As a solution for the suggested issues, efficient VDC algorithm based on precise wheel torque/speed estimation has been proposed. Proposed algorithm has been demonstrated through some practical simulations with Carsim and Simulink. As some expected future works, 1. Optimal torque distribution to minimize side-slip angle, 2. Substitute motor modeling to real motor to realize HILS(Hardware In the Loop Simulation) system.

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