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TITLE Decoupling Control of β and γ for high peformance AFS and DYC of 4 Wheel Motored Electric Vehicle

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1 Introduction

Recently much research on automobiles with active safety technology has been carried out in automobile industry. In active safety technology, improving the vehicle stability is most effective to prevent danger from occurring. Direct Yaw Moment Control (DYC) and 4 Wheel Steering (4WS) are major methods. In DYC, the control input is the torque difference between right and left wheels. The controller performs with vehicle's chassis motion. In 4WS, the control input is the rear steering angle.

Electric Vehicle has evident advantages over internal combustion engine vehicles[1][2]. These advantages can be summarized as follows:

- Electric motor can generate bi-directional torque (accelerating and decelerating) very quickly and accurately
- More than one electric motor can be mounted on each EV.
- Motor torque can be measured easily

If the actuator is fast enough as motor, we can fully apply advanced theory, like DYC[3][4]. But there is a limit in effectiveness of DYC because DYC controls the only yaw rate. So this paper proposes the integrated control of DYC and Active Front Steering (AFS). Control input of AFS is the compensated front steering angle and AFS controls the side slip angle. If Electric Power Steering (EPS) becomes widely used, AFS will be lower in cost than rear wheel steering control.

In order to avoid the mutual interference between AFS and DYC. this paper proposes the integrated control of AFS and DYC by decoupling the side slip angle and the yaw rate.

2 Vehicle Model

Figure 1 shows the 4 wheel model of 4 wheel motored EV. This vehicle model has three degrees of freedom, the yaw, lateral, and longitudinal motions. The governing equations of the lateral and yaw motions of vehicle is be expressed as follows[5]:

$$\begin{aligned} MV(\dot{\beta}+\gamma) &= F_{Yfr}+F_{Yfl}+F_{Yrr}+F_{Yrl} && (1)\\ I\dot{\gamma} &= l_f(F_{Yfr}+F_{Yfl})-l_r(F_{Yrr}+F_{Yrl})+N && (2)\end{aligned}$$

$$N=\frac{d}{2}(F_{Xfr}-F_{Xfl}+F_{Xrr}-F_{Xrl}) \qquad (3)$$

In the above equations, M denotes the mass of the body, β the side slip angle, γ the yaw rate, F_{Yf} and F_{Yr} the lateral forces of front wheels and rear wheels, F_{Xf} and F_{Xr} the longitudinal

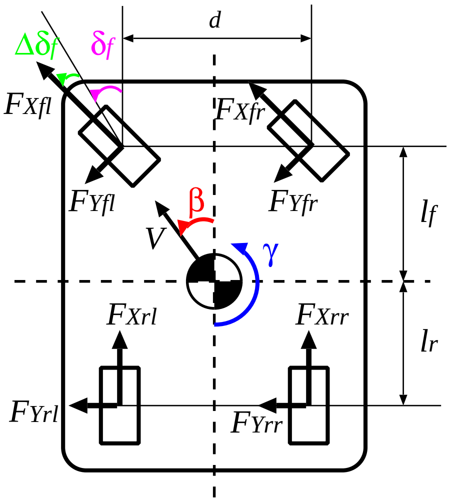

Figure 1: 4 Wheel Model of the Vehicle

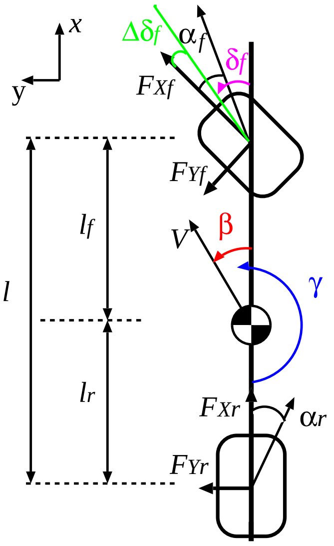

Figure 2: 2 Wheel Model of the Vehicle

forces of front wheels and rear wheels, δ_f the front wheel steering angle, l_f and l_r the distance from the center of gravity to the front wheel axle and the rear wheel axle, I the moment of inertia concerning the yaw motion, d tread.

Figure 2 shows the linear 2 wheel model of vehicle. The governing state space equation of this vehicle model is expressed as follows:

$$\dot{\boldsymbol{x}} = A\boldsymbol{x} + B\boldsymbol{u} + H\delta_f \tag{4}$$

$$\boldsymbol{x} = \begin{bmatrix} \beta \\ \gamma \end{bmatrix}, B = \begin{bmatrix} \frac{2C_f}{MV} & 0 \\ \frac{2l_fC_f}{I} & \frac{1}{I} \end{bmatrix} \tag{5}$$

$$A = \begin{bmatrix} -2\frac{C_f+C_r}{MV} & -1-2\frac{l_fC_f-l_rC_r}{MV^2} \\ -2\frac{l_fC_f-l_rC_r}{I} & -2\frac{l_f^2C_f+l_r^2C_r}{IV} \end{bmatrix} \tag{6}$$

$$\boldsymbol{u} = \begin{bmatrix} \Delta\delta_f \\ N \end{bmatrix}, H = \begin{bmatrix} \frac{2C_f}{MV} \\ \frac{2C_fl_f}{I} \end{bmatrix} \tag{7}$$

In the above equations, N denotes the yaw moment generated from the torque difference between right and left wheels, $\Delta\delta_f$ the compensated front steering angle, C_f and C_r the cornering stiffness of front tires and rear tires respectively.

3 Control System Design

In order to improve the stability of the Vehicle, it is important to control the side slip angle and the yaw rate, so it is desired for control system to have two control input. Integrated control of AFS and DYC has two control input, the yaw moment and the compensated front steering angle. In this paper a method of integrated control is decoupling of the side slip angle and the yaw rate. It is able to use the each strategy of AFS and DYC when they are used by themselves as it is.

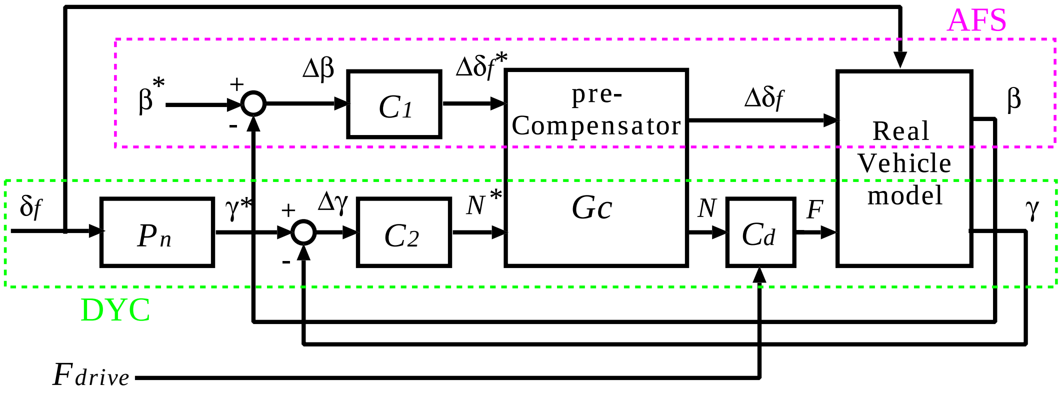

Figure 3: Block Diagram of Decoupling Controller

Figure 3 shows the block diagram of this decoupling control system. C_1 generates the desired value of the compensated front steering angle from the difference between the desired side slip angle and the real side slip angle. C_2 generates the desired value of the yaw moment from the difference between the desired yaw rate and the real yaw rate. G_c is the pre-Compensator of decoupling. C_d distributes the driving and braking force. In order to improve the stability of the vehicle, the side slip angle and the yaw rate of vehicle are controlled to trace their desired values. The desired value of the side slip angle is constantly zero. The desired value of the yaw rate is expressed as follow:

$$\gamma^* = P(0)\frac{1}{1 + T_\gamma^* s}\delta_f(s) \tag{8}$$

3.1 Design of the pre-Compensator G_c

Figure 4 shows that the pre-Compensator $G_c(s)$ decouples the side slip angle and the yaw rate.

$G_p(s)$ is the transfer function matrix from N and $\Delta\delta_f$ to β and γ in linear 2 wheel vehicle model.

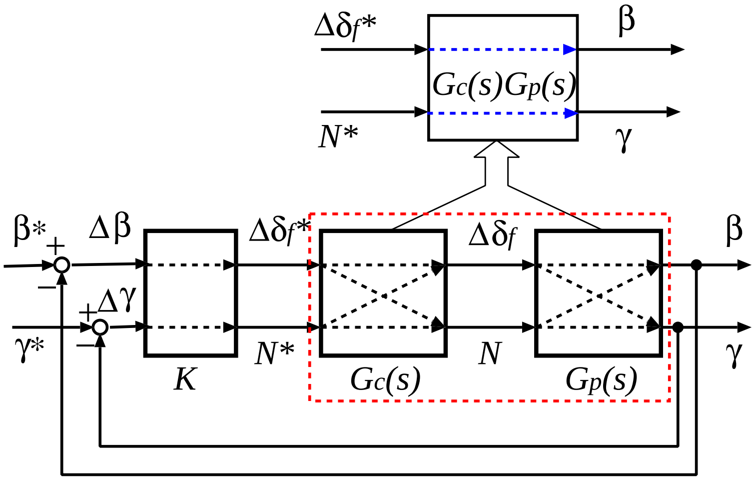

Figure 4: Decoupling of β and γ

$$\begin{bmatrix} \beta \\ \gamma \end{bmatrix} = G_p(s) \begin{bmatrix} \Delta\delta_f \\ N \end{bmatrix} \tag{9}$$

If the product of $G_c(s)$ and $G_p(s)$ is a diagonal matrix, the side slip angle and the yaw rate can be decoupled. But to let them decoupled in all frequency band, $G_c(s)$ will become more complicated.

In case of decoupling direct current part, G_c is a constant matrix. The pre-Compensator G_c can be expressed as follows:

$$\begin{aligned} G_c &= G_p^{-1}(0) \qquad (10) \\ &= \begin{bmatrix} G_{11} & G_{12} \\ G_{21} & G_{22} \end{bmatrix} \qquad (11) \end{aligned}$$

G_{11},G_{12},G_{21} and G_{22} are the matrix elements of G_c. $G_p(s)$ and G_c include a parameter, vehicle velocity. Figure 4 shows G_{11},G_{12},G_{21} and G_{22} when vehicle velocity is variable.

Each element can approach the linear curve. G_c can be expressed as a simple constant matrix, so it is easy to decouple the side slip angle and the yaw rate in every vehicle velocity.

4 Conclusion

To improve the stability of vehicle's lateral motion, the integrated control of AFS and DYC is proposed. In order to avoid the mutual interference between DYC and AFS, a decoupling control of the side slip angle and the yaw rate is shown.

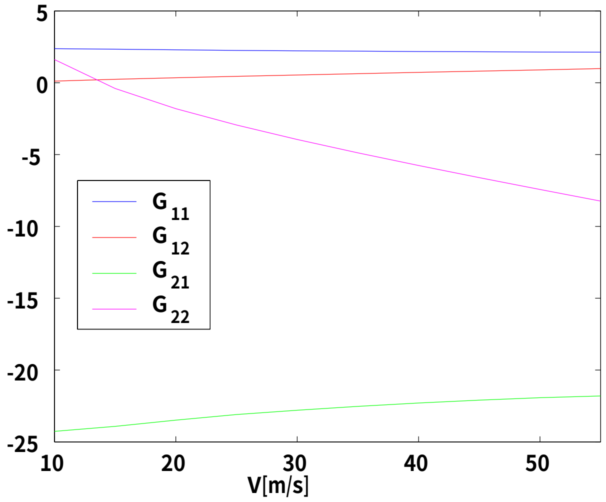

Figure 5: Relation between Elements of the matrix G_c and Vehicle Velocity

When decoupling the direct or low frequency components, it is approved that the simplification of the proposed controller is available even if the element of pre-Compensator is made to be variable with respect to the vehicle velocity.

5 Future Research

The actual controller design will be implemented in the future, applying the strategy shown in this paper. To demonstrate the effectiveness of the decoupling method shown in this paper, a road test using our newly-made experimental EV ”UOT March-II” will be implemented.

”UOT(University of Tokyo) Electric March II” is our novel experimental EV. It is 4 wheel motored EV: every wheel has its own driving motor. Each motor can be fully driven independently. This EV can generate the yaw moment very quickly and accurately and it has Electric Power Steering, so it has adequate devices for motion control experiments.

Figure 6: Photo of turning experiments with "UOT Electric March II"

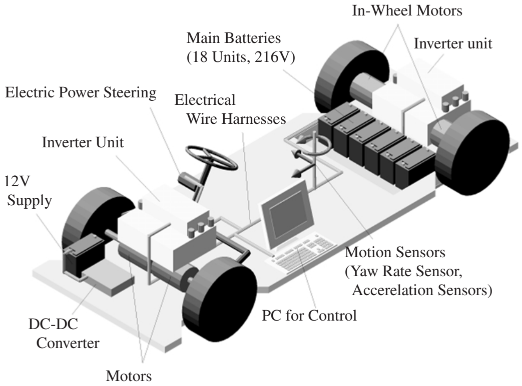

Figure 7: Configuration of "UOT Electric March II"

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