Decoupling of an EV Active Steering and Direct Yaw Moment Control Systems

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Abstract: - By considering a four-wheel-motor EV, the present paper addresses the EV stabilization using the advantages of electrical motorized wheels incorporation. The decoupling of the control of the active steering control (AFS) and the direct yaw moment control (DYC) as a way of controlling the vehicle’s body slip angle and its yaw rate simultaneously, also allows the stabilization of the lateral motion of the EV.

Key-Words: - Direct yaw moment control, active steering control, decoupling control, EV

1 Introduction

Behind recent developments of PEV, HEV and FCV, strong incentive lies in energy efficiency and global environmental problem [1]. However, it is not well recognized that the most distinct advantage of electric vehicle is in the quick and precise torque generation of electric motor. If we do not use this merit, EV cannot be used more often on the future. For example, EV cannot keep advantage in the efficiency and the emission of CO2 against future Diesel-HEV, whose energy consumption will be very low [2]. The merit of the Electrical Motorised Wheels motor as an actuator for EV’s is summarized in [3]: Torque response is fast and accurate; The motor can be attached to each wheel; The motor can generate the torque both to the direction of acceleration and deceleration.

The advantages of the electric motorised wheel will open the new possibility of novel vehicle motion control for electric vehicles. The final target is to realize a novel vehicle control system with four independently controlled in-wheel motors as depicted in Figure 1 and Figure 2.

Fig.1 - Sketch of the future EV [1]

These pictures show the integrated system with “minor feedback control loop at each wheel” and “total chassis controller” as outer weak feedback loop. The resulting MFC (Model Following Control) is drawn as an example of the minor loop. This is a controller that allows the motor to follow a specific model of a tire in an adhesive region. Typically very short time delay is required for the actuator to perform such effective feedback control.

Fig.2 - Control System in the future EV

The EV proposed is design to perform experiments on novel control techniques [4]. The most remarkable feature of this EV is that an in-wheel motor is mounted in each wheel. We can control each wheel torque completely independently. Regenerative braking is also available. The proposed EV is obtained by remodelling an existing vehicle.

In the field of lateral stabilization research of vehicle’s motion control, most of the controllers presented are SISO ones, design to control variables such as $\beta$ (body slip angle), $\gamma$ (yaw rate) or $\alpha_y$. 
Electric Power Steering

Electrical Motorised Wheel

Fig. 3 - Control Inputs $N$ and $\Delta \delta_f$

(lateral acceleration). Also most of the control goals have been either “the stabilized cornering” or “the good response to the steering input”, which are trade-off goals between them [5]. Although these two goals are the important ones, its simultaneous achievement hasn’t been fulfilled satisfactory at the same time yet. In this paper, the approach proposed tries to achieve these two goals at a time by controlling the two variables, $\beta$ and $\gamma$. This is achieved by suppressing $\beta$ in the steady state, to prevent body slip, while $\gamma$ is forced to a first order lag of the driver’s steering input so that the driver won’t feel that the driving is troubled by the lateral stability control.

Since $\beta$ and $\gamma$ are interfering to each other, it is difficult to apply this kind of complex control to internal combustion engine vehicles because the actuator response is slow. However, as mentioned before, the motor’s torque response is fast enough to be applied to perform complex control algorithms. Due to that in this paper a way to decouple the control of $\beta$ and $\gamma$ is proposed.

2 Two-Wheeled Model of the Vehicle

To control two variables, two inputs are needed. By deciding to have the compensate the yaw moment ($N$), which comes from the difference between the left and the right wheel motor torque, and the compensated front steering angle ($\Delta \delta_f$), as the two control inputs, the resulting simplified schematics of the problem are the ones presented in Figure 3.

As presented in figure 3, $N$ is generated by direct yaw moment control method (DYC) whose actuators are the independently driven motors. The $\Delta \delta_f$ is generated by active front steering control method (AFS) whose actuator is the electric power steering unit (EPS), whose behaviour as been referred in [5].

To obtain the state equations of the vehicle the two-wheeled equivalent model of the vehicle shown in Figure 4 was used [6].

In figure 4, by using the control inputs $N$ and $\Delta \delta_f$, the state equation of the vehicle model is shown as follows in (1).

\[
\dot{x} = Ax + Bu + H \delta_f
\]  \hspace{1cm} (1)

Being $\delta_f$ the steering angle, and the remaining variables given by (2).

\[
x = \begin{bmatrix} \beta \\ \gamma \end{bmatrix}, \quad u = \begin{bmatrix} \Delta \delta_f \\ N \end{bmatrix}
\]  \hspace{1cm} (2)
And the arrays in (1) are given by (3).

\[
A = \begin{bmatrix}
-2\frac{C_f + C_r}{MV} & -1 - 2\frac{l_f C_f - l_r C_r}{MV^2} \\
-2\frac{l_f C_f - l_r C_r}{l} & -2\frac{l_f^2 C_f - l_r^2 C_r}{IV}
\end{bmatrix},
\]

\[
B = \begin{bmatrix}
\frac{2C_f}{MV} & 0 \\
\frac{2l_f}{l} & 1
\end{bmatrix}
\text{and } H = \begin{bmatrix}
\frac{2C_f}{MV} \\
\frac{2l_f}{l}
\end{bmatrix}
\]

The parameters included in the arrays are constants and refer either to fixed distances or well known mechanical parameters.

The proposed model is used to calculate the controller parameters.

### 3 Control System

In figure 5 the block diagram of the whole control system including the decoupling control of AFS and DYC is presented. The proposed controllers are linear, i.e. classical PID controllers are used for AFS and DYC, respectively.

Each controller has the decoupling block one of which is shown in Figure 6.

In figure 6 it is shown the disturbance-observer-formed decoupling controller for AFS block that detects and removes the unwanted effect from DYC block. The other block not shown here is also the disturbance-observer-formed decoupling controller for DYC block that detects and removes the unwanted effect from AFS block.

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### Fig. 5 - Block Diagram of the AFS and DYC Control Systems

### Fig. 6 - Block Diagram of the Decoupling Control
Fig. 7 - Simulation Result of the Decoupling Control with Step Input $\delta_j = 9[\text{deg}]$

4 Simulation Results
To assess the behaviour of the proposed decoupling control model a simulation was performed. Figure 7 shows the obtained results when the vehicle is assumed to softly accelerate and at $t=3$ s the driver gives 9 degrees of step steering angle input to the front wheel.

By analyzing figure 7 it can be seen that when the proposed decoupling control is implemented, the controlled values $\beta$ and $\gamma$ are both closer to the command value, i.e. follows the reference signals. Also from this simulation result it is visible that the unwanted yaw moment (N) was reduced due to this decoupling controller approach.

Another observed side effect of this approach is the reduction in the demand of the electrical energy demand for the simulated situation that can lead to an extension of the driving range of these electrical vehicles per battery charge.

5 Conclusion
The present paper addresses the EV stabilization using the advantages of electrical motorized wheels incorporation into a four-wheel-motor topology. By designing the decoupling of the control of the
dactive steering control (AFS) and the direct yaw moment control (DYC) it was shown that it is a way of controlling the vehicle’s body slip angle and its yaw rate simultaneously. This approach also indicates that it allows the stabilization of the lateral motion of the EV.

The EV with an independently controlled in-wheel-motor installed in each wheel was proposed to allow the implementation of this new approach.

By resorting to numerical simulation results, that are shown in this work, the proposed decoupling controller of AFS and DYC as an example of complex lateral motion control was proven.

References: