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Simulation of Driver Control for an Electric Vehicle

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Abstract: This work presents a design and simulation of electric vehicle driver control. A driver controller is responsible of generating suitable values of control inputs that ensures accurate vehicle trajectory tracking. A good driver controller is needed to study vehicle motion and comfort, energy consumption, electronic stability control, electronic brake force distribution, antilock braking system, suspension system, etc. In this paper, simple PID controllers are designed, tuned and simulated. Simulations results show accurate trajectory tracking of an electric vehicle.

Keywords: Electric vehicle, driver controller, dynamic vehicle model.

1. INTRODUCTION

Electric vehicles (EVs) are driven by one or more electric motors. On the other hand, conventional vehicles have a propulsion system that is solely powered by an internal-combustion engine (ICE). Hybrid electric vehicles (HEVs) are powered by both ICEs and electric motors. In this work, our system of interest is an electric vehicle.

When it comes to vehicles, to effectively study, analyze and design subsystems such as electronic stability control, electronic brake force distribution, antilock braking system, suspension system, energy consumption, etc., the vehicle has to be put in motion first. In simulation works, that necessitates the implementation of driver control. In this work, a driver controller is designed, tuned and simulated for an electric vehicle.

The outline of this paper is as follows. In Section 2 the mathematical model of an electric vehicle is described. Sections 3 elaborates a driver controller design and simulation results, followed by Section 4 that concludes this paper.

2. MATHEMATICAL MODEL

In this section, the mathematical model of an electric vehicle is presented.

2.1 Rigid Body Dynamics

Assuming that the passenger car is rigid body the Newton-Euler equations of motion are given by [1]

$$\begin{aligned}
m\ddot{x}_b &= m\left(\dot{y}_b\dot{\psi} - \dot{z}_b\dot{\theta}\right) + F_{sx} \\
m\ddot{y}_b &= m\left(\dot{z}_b\dot{\phi} - \dot{x}_b\dot{\psi}\right) + F_{sy} \\
m\ddot{z}_b &= m\left(\dot{x}_b\dot{\theta} - \dot{y}_b\dot{\phi}\right) + F_{sz} \\
J_x\ddot{\phi} &= \dot{\theta}\dot{\psi}\left(J_y - J_z\right) + M_{sx} \\
J_y\ddot{\theta} &= \dot{\psi}\dot{\phi}\left(J_z - J_x\right) + M_{sy} \\
J_z\ddot{\psi} &= \dot{\phi}\dot{\theta}\left(J_x - J_y\right) + M_{sz}
\end{aligned} \tag{1}$$

The external forces and moments that act on the vehicle is shown in Figure 1.

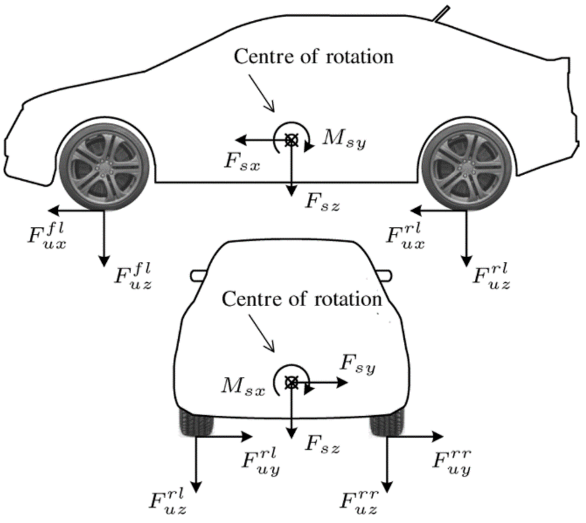

Figure 1. External Forces and Moments Acting on an EV

2.2 Unsprung Mass External Forces

The sum of external forces $F_s = [F_{sx} \quad F_{sy} \quad F_{sz}]$ acting on sprung mass of the vehicle is given by

$$F_s = RF_u \tag{2}$$

where $F_u = [F_{ux} \quad F_{uy} \quad 0]$. The x unsprung mass external force is given by

$$F_{ux} = F_{ux}^{fl} + F_{ux}^{fr} + F_{ux}^{rl} + F_{ux}^{rr}$$

where

$$\begin{aligned}
F_{ux}^{fl} &= F_{tx}^{fl}\cos\delta - F_{ty}^{fl}\sin\delta - R^{fl} - F_a/4 \\
F_{ux}^{fr} &= F_{tx}^{fr}\cos\delta - F_{ty}^{fr}\sin\delta - R^{fr} - F_a/4 \\
F_{ux}^{rl} &= F_{tx}^{rl} - R^{rl} - F_a/4 \\
F_{ux}^{rr} &= F_{tx}^{rr} - R^{rr} - F_a/4
\end{aligned}$$

The tire rolling resistance force is given by [2]

$$R^i = C_R F^i_{uz}, \qquad i = fl, fr, rl, rr$$

The equivalent aerodynamic drag force acting on the vehicle is given by [2]

$$F_a = \frac{1}{2}\rho C_d A_F(\dot{x}_b + V_{wind})^2$$

where the vehicle frontal area is given by [3]

$$A_F = 1.6 + 0.00056(m - 765).$$

The y unsprung mass external force is given by

$$F_{uy} = F^{fl}_{uy} + F^{fr}_{uy} + F^{rl}_{uy} + F^{rr}_{uy}$$

where

$$\begin{aligned} F^{fl}_{uy} &= F^{fl}_{ty}\cos(\delta) + F^{fl}_{tx}\sin(\delta) \\ F^{fr}_{uy} &= F^{fr}_{ty}\cos(\delta) + F^{fr}_{tx}\sin(\delta) \\ F^{rl}_{uy} &= F^{rl}_{ty} \\ F^{rr}_{uy} &= F^{rr}_{ty}. \end{aligned}$$

2.3 Tire Forces

The longitudinal and lateral tire forces are given by [4]

$$\begin{aligned} F^i_{tx} &= \frac{\sigma^i_x}{\sigma^i}F^i_t \\ F^i_{ty} &= \frac{\sigma^i_y}{\sigma^i}F^i_t, i = fl, fr, rl, rr, \end{aligned} \tag{3}$$

respectively, where

$$\begin{aligned} F^i_t &= 2\mu^i F^i_{uz}\{\frac{C_f\sigma^i}{\mu^i F^i_{uz}} - \frac{1}{3}(\frac{C_f\sigma^i}{\mu^i F^i_{uz}})^2 + \frac{1}{27}(\frac{C_f\sigma^i}{\mu^i F^i_{uz}})^3\}, \\ &\qquad \text{if}\frac{C_f\sigma^i}{\mu^i F^i_{uz}} \le 3 \\ F^i_t &= 2\mu^i F^i_{uz}, \text{if}\frac{C_f\sigma^i}{\mu^i F^i_{uz}} > 3, i = fl, fr, rl, rr. \end{aligned}$$

The total slip is given by

$$\sigma^i = \sqrt{(\sigma^i_x)^2 + (\sigma^i_y)^2}, i = fl, fr, rl, rr$$

where

$$\begin{aligned} \sigma^i_x &= \frac{\omega^i r - \dot{x}_b}{\omega^i r} \\ \sigma^i_y &= \frac{\dot{x}_b}{\omega^i r}\tan(\alpha^i), i = fl, fr, rl, rr. \end{aligned}$$

The tire slip angles (see Figure 2) are given by

$$\begin{aligned} \alpha^{fl} &= \delta - \tan^{-1}(\frac{\dot{y}_b + l_f\dot{\psi}}{\dot{x}_b + d_l\dot{\psi}}) \\ \alpha^{fr} &= \delta - \tan^{-1}(\frac{\dot{y}_b + l_f\dot{\psi}}{\dot{x}_b - d_r\dot{\psi}}) \\ \alpha^{rl} &= -\tan^{-1}(\frac{\dot{y}_b - l_r\dot{\psi}}{\dot{x}_b + d_l\dot{\psi}}) \\ \alpha^{rr} &= -\tan^{-1}(\frac{\dot{y}_b - l_r\dot{\psi}}{\dot{x}_b - d_r\dot{\psi}}). \end{aligned}$$

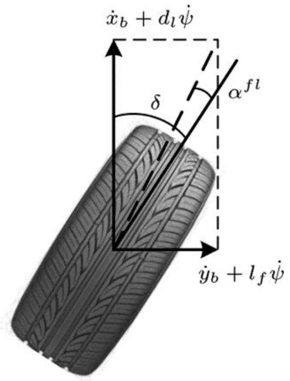

Figure 2: Front-left tire slip angle

The tire-road friction coefficient is given by

$$\mu^i(\sigma^i, \dot{x}) = (C_1(1 - e^{-C_2\sigma^i}) - C_3\sigma^i)e^{-C_4\sigma^i\dot{x}_b}$$

where C_1, C_2, C_3 and C_4 are parameters that depend on tire and road conditions, determined from experiments (see Table 1) [5].

Table 1: Tire-Road Friction Parameters

Surface condition	C_1	C_2	C_3	C_4
Asphalt, dry	1.029	17.16	0.523	0.03
Asphalt, wet	0.857	33.822	0.347	0.03
Snow	0.1946	94.129	0.0646	0.03

2.4 External Moments

The sum of external moments acting on sprung mass of the vehicle about x, y and z axes is given by

$$\begin{aligned} M_{sx} &= -m\ddot{y}_b h - M_\phi + M_{gx} + M_{sfx} \\ M_{sy} &= m\ddot{x}_b h - M_\theta + M_{gy} + M_{sfy} \\ M_{sz} &= M_{sfz} \end{aligned} \tag{4}$$

respectively, where

$$\begin{aligned} [M_{sfx} \quad M_{sfy} \quad M_{sfz}]^\top &= R[0 \quad 0 \quad M_{ufz}]^\top \\ M_{ufz} &= (F^{fl}_{ux} + F^{rl}_{ux})d_l - (F^{fr}_{ux} + F^{rr}_{ux})d_r \\ &\quad +(F^{fl}_{uy} + F^{fr}_{uy})l_f - (F^{rl}_{uy} + F^{rr}_{uy})l_r \end{aligned}$$

and

$$[-M_{gy} \quad M_{gx} \quad (\cdot)]^\top = R[0 \quad 0 \quad mgh]^\top.$$

2.5 Wheel Dynamics

The wheel dynamics are given by

$$J_w \dot{\omega}^i = T_w^i - F_{tx}^i r - T_b^i, i = fl, fr, rl, rr. \qquad (5)$$

In this section the mathematical model of an electric vehicle is explored. As presented, the electric vehicle dynamics can be broken into several parts i.e. rigid body dynamics, unsprung mass external forces, tire forces, external moments and wheel dynamics. Most of these different components influence each other and affect the outputs of an electric vehicle.

3. DRIVER CONTROLLER DESIGN

In studies related to energy consumption, electronic stability control, antilock braking system, traction control, electronic brake distribution, etc. of an electric vehicle, the vehicle has to be steered according to a predetermined velocity profile. For that reason, an accurate driver control mechanism is essential.

Referring to the electric vehicle dynamics (Equations (1-5)) presented in Section 2, the control inputs to the system are wheel torque T_w^i and steering angle δ. Thus, a driver controller has to be designed for the generation of T_w^i and δ to achieve a desired vehicle trajectory. The control architecture is shown in Figure 3.

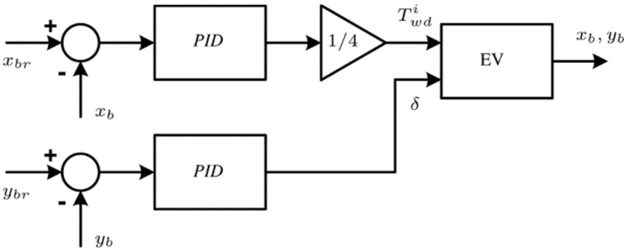

Figure 3. Driver Control Architecture

Simple PID controllers are tuned and a simulation of the electric vehicle motion for trajectory tracking is shown in Figures 4 and 5.

The figures show the EV x and y reference and actual positions. Despite the complexity of the mathematical model of the electric vehicle, the PID controllers perform well in the trajectory tracking.

4. CONCLUSION

In this work, simple PID controllers are tuned to enable electric vehicle driver control. Simulation results show that despite the simplicity of the driver controllers, the trajectory tracking is carried out well. Given the controller design and simulation results, it can be concluded that the electric vehicle driver control approach can be applied to carry out other relevant studies and research works that require vehicle motion.

REFERENCES

[1] Bera, T. K., Bhattacharya, K. and Samantaray, A.K. (2011) ‘Evaluation of antilock braking system with an integrated model of full vehicle system dynamics’, *Simulation Modelling Practice and Theory*, Vol. 19, No. 10, pp. 2131-2150.

[2] Rajamani, R. (2012) *Vehicle Dynamics and Control*, Hardcover, October 2006.

[3] Wong, J. Y. (2001) Theory of Ground Vehicles, 3rd ed., Wiley-Interscience.

[4] Jin-Oh Hahn, R. Rajamani and L. Alexander, "GPS-based real-time identification of tire-road friction coefficient," in *IEEE Transactions on Control Systems Technology*, vol. 10, no. 3, pp. 331-343, May 2002.

[5] T.K. Bera, K. Bhattacharya, A.K. Samantaray, Evaluation of antilock braking system with an integrated model of full vehicle system dynamics, Simulation Modelling Practice and Theory, Volume 19, Issue 10, November 2011, Pages 2131-2150, ISSN 1569-190X

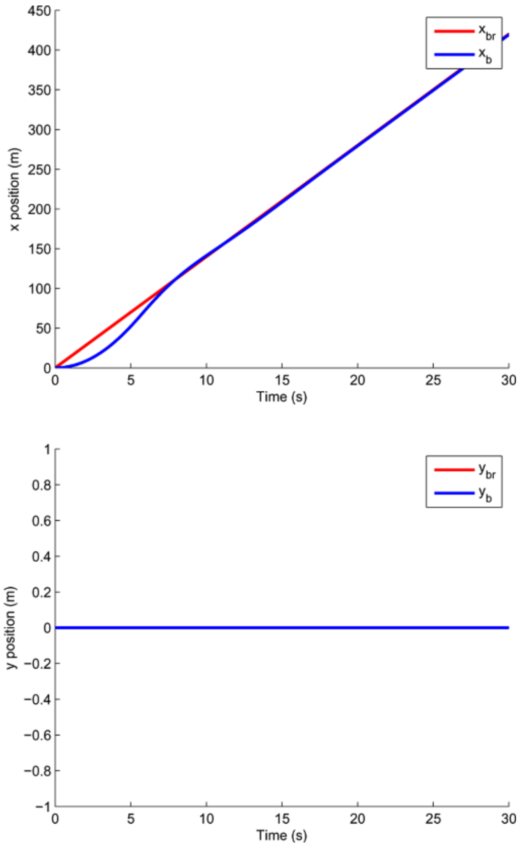

Figure 4. Straight Line Trajectory Tracking

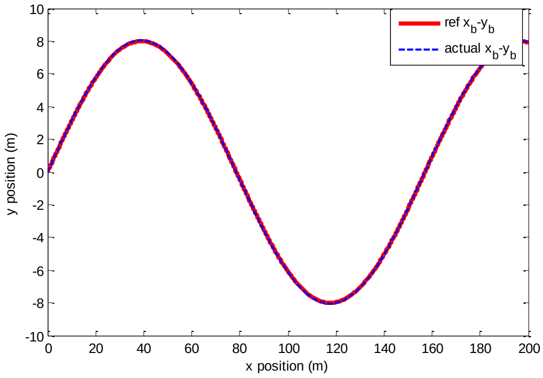

Figure 5. Sinusoidal Trajectory Tracking