Dynamics Modeling of The Punctured Vehicle

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Abstract

The problem of traffic safety has become increasingly prominent, due to the intensive traffic flow and the speeding up of vehicles. One of the major causes of major traffic accidents was vehicle punctured.The paper aims at punctured vehicle, based on kinetic theory, the 7-DOF dynamics model including horizontal, vertical , yaw and rotational movement of the four wheels is established.

Keywords

Dynamics Modeling, Punctured Vehicle, Tire Model.

1. Introduction

Due to the substantial increase in vehicle ownership, the unprofessionalization of drivers, the intensive traffic flow and the speeding up of vehicles, the problem of traffic safety has become increasingly prominent. One of the major causes of major traffic accidents was vehicle punctured, especially in the case of traffic accidents on expressways. The reason is even more obvious and prominent. Therefore, the dynamic modeling of the vehicle under the punctured condition is not only important in theoretical significance, but also great practical valuable.

2. Dynamics Model of Punctured Vehicle

Aimed at the vehicle dynamics modeling, many scholars conducted a detailed and in-depth study. The current vehicle dynamics model mainly includes full vehicle model, 1/2 vehicle model, 1/4 vehicle model, 2-DOF model and various types Complex multi-degree-of-freedom model. According to the 6-DOF model of H.Pham in UC Berkeley, a four-DOF dynamic model based on steering stability and roll stability is established by Chu Duanfeng, The research object of this paper is the punctured vehicle, which needs independent research on four wheels. Therefore, based on the kinetic model of Chu Duanfeng and the unitire tire model of Guo Konghui, this paper establishes a model of 7-DOF dynamics model including horizontal, vertical, yaw and rotational movement of the four wheels.

2.1 Coordinate system of vehicle movement

In order to establish the required vehicle dynamics model, the coordinate system of the vehicle movement needs to be established first. The coordinate system established in this paper includes two interrelated coordinate rectangular coordinate systems, which is shown in Fig.1.

Coordinate system OXYZ is fixed to the ground, which is the inertial coordinate system, the origin dot O is fixed at the starting point of the vehicle movemont. Coordinate system O'X'Y'Z ' is fixed at the vehicle, which is the vehicle coordinate system, the origin dot O’ is fixed at the center of gravity of the vehicle. The r_o in the figure shows the relative displacement between the coordinate system O'X'Y'Z ' and the coordinate system OXYZ, the ω_o in the figure shows the relative angular speed between the coordinate system O'X'Y'Z ' and the coordinate system OXYZ. Neglecting the pitch and vertical movement of the vehicle, the 7-DOF motion equation including horizontal, vertical , yaw and rotational movement of the four wheels can be derived according to the relative movement relationship between the two coordinate systems.

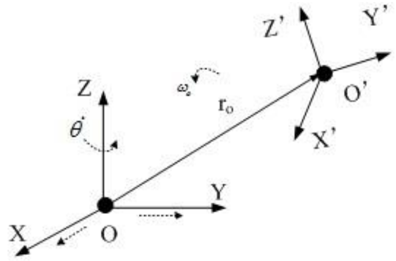

Fig.1 Relative coordinate system of vehicle dynamics model

Assuming the longitudinal and lateral velocities of the vehicle are v_x and v_y, the yaw angle of the vehicle is θ. Then, the relative velocity $\overset{\circ}{r}_0$, the relative acceleration $\overset{\circ\circ}{r}_0$ and the relative rotation angular velocity ω_o between the coordinate system O'X'Y'Z ' and the coordinate system OXYZ is obtained:

$$\begin{cases} \dot{r}_o = \begin{bmatrix} v_x & v_y & 0 \end{bmatrix}^T \\ \ddot{r}_o = \begin{bmatrix} \dot{v}_x - v_y\dot{\theta} & \dot{v}_y + v_x\dot{\theta} & 0 \end{bmatrix}^T \\ \omega_o = \begin{bmatrix} 0 & 0 & \dot{\theta} \end{bmatrix}^T \end{cases} \tag{1}$$

2.2 Force analysis aimed at Vehicle and each wheel

Ignoring the force of the wind on the moving vehicle, all the external forces on the vehicle come from the ground. The analysis of the force is shown in Fig.2.

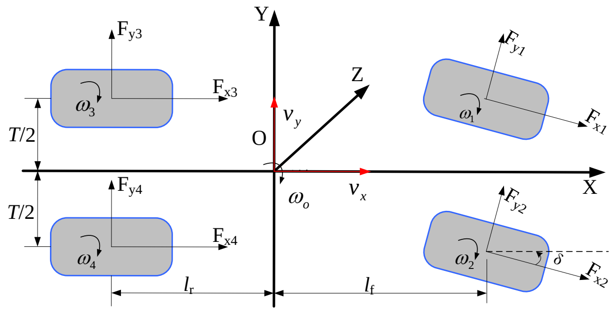

Fig. 2 Force analysis of 7-DOF vehicle

Assuming the total external forces on the vehicle in the longitudinal and lateral directions are F_x and F_y, the longitudinal forces and lateral forces on the wheels of the vehicle are F_{xi} and F_{yi} ($i = 1,2,3,4$), the steering angle of the front wheels is δ, the rotation angular velocity of each wheel is ω_i ($i = 1,2,3,4$), The distance between the left wheels and right wheels, the distance of the front and rear wheels from the center of gravity of the vehicle is respectively l_f and l_r, the mass of the vehicle is m and the yaw moment is M_z ,then:

$$F_x = (F_{x1} + F_{x2})\cos\delta + (F_{y1} + F_{y2})\sin\delta + F_{x3} + F_{x4} \tag{2}$$

$$F_y = (F_{y1} + F_{y2})\cos\delta - (F_{x1} + F_{x2})\sin\delta + F_{y3} + F_{y4} \tag{3}$$

$$\begin{aligned} M_z = &\frac{T}{2}[(F_{x1}-F_{x2})\cos\delta+(F_{y2}-F_{y1})\sin\delta] \\ &+l_f[(F_{y1}+F_{y2})\cos\delta-(F_{x1}+F_{x2})\sin\delta] \\ &+\frac{T}{2}(F_{x3}-F_{x4})+l_r(F_{y3}+F_{y4}) \end{aligned} \quad (4)$$

2.3 7-DOF Dynamics Model of vehicle

According to the force analysis of the vehicle, assuming the moment of inertia of the vehicle around the Z axis is I_z, the moment of inertia of each wheel is J_i ($i=1,2,3,4$),and the rotational angular velocity of each wheel is ω_i ($i=1,2,3,4$), then the 7-DOF dynamics model of the vehicle can be obtained as follows:

(1) Longitudinal movement

$$m(\dot{v}_x - v_y\dot{\theta}) = (F_{x1}+F_{x2})\cos\delta+(F_{y1}+F_{y2})\sin\delta+F_{x3}+F_{x4} \quad (5)$$

(2) Lateral movement

$$m(\dot{v}_y + v_x\dot{\theta}) = (F_{y1}+F_{y2})\cos\delta-(F_{x1}+F_{x2})\sin\delta+F_{y3}+F_{y4} \quad (6)$$

(3) Yaw movement

$$\begin{aligned} I_z\dot{\omega}_o = &\frac{T}{2}[(F_{x1}-F_{x2})\cos\delta+(F_{y2}-F_{y1})\sin\delta] \\ &+l_f[(F_{y1}+F_{y2})\cos\delta-(F_{x1}+F_{x2})\sin\delta] \\ &+\frac{T}{2}(F_{x3}-F_{x4})+l_r(F_{y3}+F_{y4}) \end{aligned} \quad (7)$$

(4) Rotation of the wheels

$$J_1\dot{\omega}_1 = -T_{b1} - F_{x1}R_1 \quad (8)$$

$$J_2\dot{\omega}_2 = -T_{b2} - F_{x2}R_2 \quad (9)$$

$$J_3\dot{\omega}_3 = \frac{T_d}{2} - T_{b3} - F_{x3}R_3 \quad (10)$$

$$J_4\dot{\omega}_4 = \frac{T_d}{2} - T_{b4} - F_{x4}R_4 \quad (11)$$

3. Tire Model

When the material, structure, size and pattern of the vehicle tires are all determined, the longitudinal force and lateral force of the tires depends mainly on the speed of the tire and its force in the vertical direction. Therefore, it is necessary to analyze the vertical load force of each tire.

3.1 Slip ratio and tire slip angle

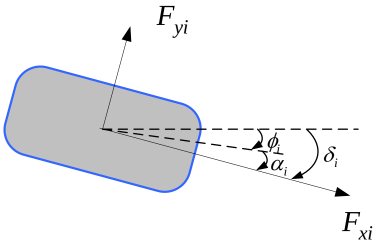

Fig.3 wheel side angle

When the vehicle is driving, the ground gives certain adhesion force to the tires. Under the action of adhesion force, the tires of the vehicle rolls and slides simultaneously. The rolling speed of each tire of the vehicle is $\omega_i R$ ($i=1,2,3,4$), assuming the linear speed of each tire in the longitudinal direction is v_{xi} ($i=1,2,3,4$), then the slip rate of each wheel is calculated as:

$$\lambda_i = \frac{v_{xi} - \omega_i R_i}{v_{xi}} \tag{12}$$

Tire side angle is the angle between the side of the tire and the direction of the tire longitudinal speed, assuming the steering angle of each tire of the vehicle is δ_i ($i=1,2,3,4$), the driving angle of each tire is ϕ_i ($i=1,2,3,4$), as shown in Fig. 3, then the tire side angle can be obtained ,which is $\alpha_i = \delta_i - \phi_i$.

3.2 The vertical load of each tire

According to the force analysis and dynamic model of the vehicle, assuming the vertical load of each tire of the vehicle is F_{zi} ($i=1,2,3,4$), the height of the center of gravity of the vehicle is h, the load equation of each tire in the vertical direction can be deduced as:

$$\begin{cases} F_{z1} = \dfrac{m}{2}\left(g\dfrac{l_r}{l_f+l_r} + \dot{v}_x\dfrac{h}{l_f+l_r} + \dot{v}_y\dfrac{hl_r}{T\left(l_f+l_r\right)} \right) \\ F_{z2} = \dfrac{m}{2}\left(g\dfrac{l_r}{l_f+l_r} + \dot{v}_x\dfrac{h}{l_f+l_r} - \dot{v}_y\dfrac{hl_r}{T\left(l_f+l_r\right)} \right) \\ F_{z3} = \dfrac{m}{2}\left(g\dfrac{l_f}{l_f+l_r} - \dot{v}_x\dfrac{h}{l_f+l_r} + \dot{v}_y\dfrac{hl_f}{T\left(l_f+l_r\right)} \right) \\ F_{z4} = \dfrac{m}{2}\left(g\dfrac{l_f}{l_f+l_r} - \dot{v}_x\dfrac{h}{l_f+l_r} - \dot{v}_y\dfrac{hl_f}{T\left(l_f+l_r\right)} \right) \end{cases} \tag{13}$$

3.3 Tire dynamics model

UniTire tire model is mainly used in the simulation analysis of vehicle handling stability. It is a semiempirical tire modeling theory proposed by Academician Guo Konghui. Unitire model has the characteristics of good theoretical boundary, high solution speed and high simulation accuracy. It is suitable for complex and extreme conditions of the tire simulation analysis. Therefore, this paper selected Unitire tire model as the basis of the establishment of a punctured tire model.

Acknowledgements

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