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Study on Orchard Vehicle Motion Stability Control System

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Abstract: This paper focuses on tipover problem of orchard vehicle, establishes vehicle dynamic model with 7 degrees of freedom (DOF), proposes a vehicle motion stability control method based on real-time adjustment of vehicle posture parameters and relies on vehicle scale model motion stability control test. Analysis of test result shows that vehicle motion stability control model mentioned above can effectively prevent orchard vehicle tipover accidents. When vehicle encounters tipover accident, angles such as pitching angle vary rapidly. In anti-tipover control process, pitching and rolling angle have greater influence on vehicle motion stability. If K_p and K_d are adjusted properly, good vehicle motion stability control effect is acquired.

Index Terms—Orchard vehicle, stability, control

1. INTRODUCTION

With development of orchard industry in China, orchard production scale and mechanization level are increasing, as well as farmers' demands for orchard machinery. Because of application to pruning, plucking, transportation and other aspects in particular environment, orchard vehicle is used more extensively in orchard production. However, orchard vehicle encounters tipover accidents frequently in operation process, threatening security of operator and assets (Bayar, G., 2013). In general, these accidents are caused because of two reasons. On one hand, orchard operation environment is relatively complex and orchard vehicle often moves on uneven and fluctuating road (Barawid, Mizushima, Ishii, Noguchi 2007). On the other hand, centroid of orchard vehicle is too high, increasing tipover risk. Hence, study on prevention of orchard vehicle tipover problem has great importance on efficiency and security of orchard operation.

At present, Chinese and other countries' studies on prevention of vehicle tipover problem are mainly located on heavy vehicle and early warning mechanism. Bizzini T. proposes an anti-tipover detection method for variable amplitude cylinder vehicles (Bizzini, T. 1988). Freitas does some research on orchard vehicle anti-tipover system based on ZigBee (Freitas, G., Hamner, B., Bergerman, M., & Singh, S. 2012). Hamner develops a stability control and early warning system installed on heavy vehicle (Hamner, B., Singh, S., & Bergerman, M. 2010). What need to point out is that orchard vehicle has particular structure characteristic and faces relatively complex road conditions, making its tipover accidents different from heavy vehicles. To put forward study on orchard vehicle active anti-tipover control, this paper establishes orchard vehicle dynamic model, proposes an orchard vehicle motion stability control method to exert active anti-tipover control over vehicle, and builds an entity vehicle model to verify above research results.

2. MODEL CREATION

2.1 Dynamic model

When moving on uneven road, orchard vehicle parameters (including centroid, pitching angle, pitching angular acceleration, rolling angle and rolling angle acceleration) vary as road fluctuates. Research on these parameters has great importance on orchard vehicle motion stability control (Shin, B. S., Kim, S. H., & Park, J. U. 2002). Based on the assumption that target vehicle is a rigid body, when moving on slope, vehicle has 7 DOF, that is, vehicle body centroid has 3 DOF on pitching, longitudinal and vertical movement, wheel dynamic model has 4 single DOF, shown in Fig.1.

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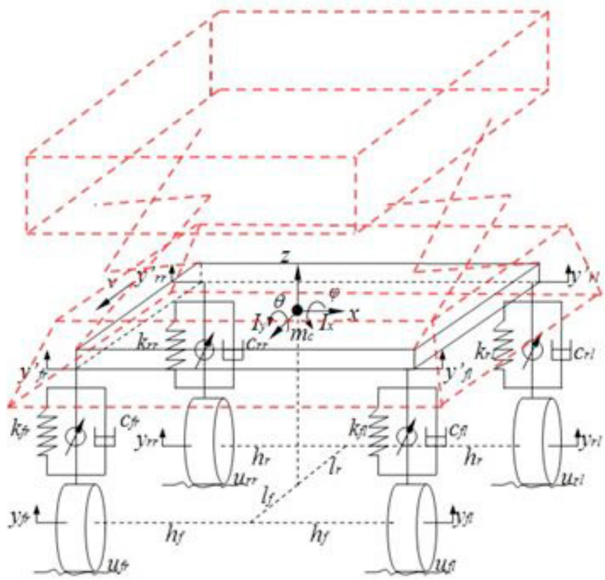

Fig.1. 7 DOF whole vehicle model

According to the Newton law, vehicle vertical movement equation is expressed as:

$$m_c(a_c - L\ddot{\varphi}) = F_{1fr} + F_{1fl} + F_{1rr} + F_{1rl} \quad (1)$$

where m_c is mass, a_c is vehicle body centroid acceleration, L is vertical distance between suspension centroid and vehicle centroid, φ is pitching angle of vehicle body, F_{li} is acting force exerted by suspension on vehicle body, $i = fl$, $i = fr$, $i = rl$ and $i = rr$ represent left front wheel, right front wheel, left rear wheel and right rear wheel respectively.

Equations of acting force exerted by suspension on vehicle body are expressed as:

$$F_{1fr} = k_{fr}(y_{fr} - y'_{fr}) + c_{fr}(\dot{y}_{fr} - \dot{y}'_{fr}) \quad (2)$$

$$F_{1fl} = k_{fl}(y_{fl} - y'_{fl}) + c_{fl}(\dot{y}_{fl} - \dot{y}'_{fl}) \quad (3)$$

$$F_{1rr} = k_{rr}(y_{rr} - y'_{rr}) + c_{rr}(\dot{y}_{rr} - \dot{y}'_{rr}) \quad (4)$$

$$F_{1rl} = k_{rl}(y_{rl} - y'_{rl}) + c_{rl}(\dot{y}_{rl} - \dot{y}'_{rl}) \quad (5)$$

where k is suspension stiffness, c is damping of suspension damper, y_{fr} , y_{fl} , y_{rr} and y_{rl} are vertical displacement of unsuspended mass at front and rear axle, y'_{fr} , y'_{fl} , y'_{rr} and y'_{rl} are vertical vibration displacement of front and rear suspension.

Equation of vehicle body pitching movement is expressed as:

$$I_y\ddot{\theta} = l_f\left(F_{1fr} + F_{1fl}\right) - l_r\left(F_{1rr} + F_{1rl}\right) \quad (6)$$

where I_y is rotary inertia of vehicle body along y axis, l_f is distance between front axle and centroid, l_r is distance between rear axle and centroid.

Equation of vehicle body rolling movement is expressed as:

$$I_x\ddot{\theta} + h_f\left(F_{1fl} - F_{1fr}\right) + h_r\left(F_{1rl} - F_{1rr}\right) = 0 \quad (7)$$

where I_x is rotary inertia of vehicle body along x axis, θ is rolling angle of vehicle body, h_f is distance between front wheel and centroid, h_r is distance between rear wheel and centroid.

2.2 Motion stability control method

When orchard vehicle crosses barriers, the most direct reflection of tipover is that wheels do not have contact force on ground. It means that in extreme state, contact force on ground exerted by tires should meet the following need:

$$|u| \geq 0 \quad (8)$$

When vehicle approaches critical point of instability, inertia force is exerted on vehicle body to make tires meet needs of equation (8) at some extent.

Vehicle tipover problem is mainly depicted with vehicle body pitching angle, which can be taken as control target to determine acceleration. Specifically speaking, pitching angle of vehicle body is measured by sensors in