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Anti-Rollover Control Based on Fuzzy Differential Braking for Heavy Duty Commercial Vehicle

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Abstract: The rollover warning system based on 3 degree of freedom(DOF) rollover vehicle model, which designed lateral-load transfer ratio as the control objective, additional yaw moment got with fuzzy control algorithm, distributing braking force to the wheel according to differential braking. The typical conditions of steering wheel sine input was selected, the results in Matlab/Simlink showed that the anti-rollover control system could greatly improve the rollover and yaw stability, prevent the rollover happen.

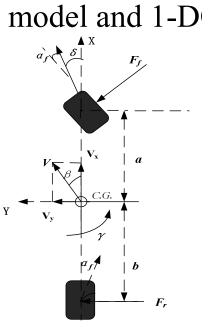
Introduction

With the developing of economy and logistics industry, the heavy commercial vehicles got widely used and developed, meaning while, the safety and stability also attached much attention. It is easy to rollover in the driving due to the particular structure, brings about huge property loss and casualties. According to statistics,20% casualties caused by rollover in Europe and North American, so there is no time delay to deal with rollover problem.

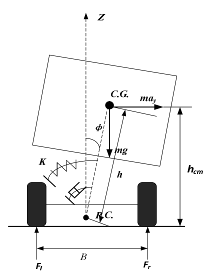
The rollover of vehicle had been researched in the domestic. It focused on active suspension, active steering ,differential braking and other control methods. Established 3-DOF rollover vehicle model, the LTR as the control objective with fuzzy control, work out the additional yaw moment and make anti-rollover control came true by differential braking.

The reference model of rollover

Established 3-DOF rollover vehicle model, the Fig.1 is the 3-DOF rollover model, which contains 2-DOF bike model and 1-DOF rollover model.



(a) 2-DOF bike model



(b) Banking degree of freedom

Fig.1 3-DOF rollover model

According to D'Alembert's principle and Newton's second law, got the lateral, yaw and later dynamics balance equation as follow:

$$ma_y - m_s h\ddot{\phi} = F_f \cos\delta + F_r \tag{1}$$

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$$I_z\dot{\gamma} = F_f a\cos\delta - F_r b \quad (2)$$

$$I_{xeq}\ddot{\phi} = ma_y h\cos\phi + m_s gh\sin\phi - c\dot{\phi} - k\phi \quad (3)$$

Where ,m is the vehicle mass, m_s is sprung mass, g is gravitational acceleration, a_y is centroid lateral acceleration, ϕ is roll angle, k/c are equivalent lateral stiffness, damping factor of suspension, h is the distance from centroid to roll center, h_{cm} is centroid height, a_f/a_r are the slip angle of front/rear tire, k_f/k_r are cornering stiffness of the front/rear tire, F_f/F_r are the front/rear tire lateral force, δ is front wheel steering angle, a/b is the distance from centroid to front/rear axis, β is side slip angle, v_x/v_y are centroid longitudinal/side velocity, γ is yaw velocity, I_{xeq} is moment inertia sprung mass around roll axis, I_x and I_z are moment inertia vehicle around X axis and Z axis.

The rollover warning system

The rollover index

Vehicle rollover index is vital for rollover warning and active anti-rollover. LTR is rollover index, defined as the specific value between left/right vertical load and the whole vertical load, the formula as follow:

$$LTR = \frac{F_l - F_r}{F_l + F_r}. \quad (4)$$

From LTR definition, it suits different vehicles and road conditions, which was widely used, it is difficult to measure the vertical load of two sides, it could be transformed as:

$$|LTR| = \left|\frac{2}{mgB}\left[m_s(a_y - h\ddot{\phi})(h_{cm} - h\phi) + k\phi + c\dot{\phi}\right]\right|. \quad (5)$$

From the fifth formula, the value of LTR had a relationship with move condition and vehicle structure parameters, if move condition parameter can be measured or estimated, the value of LTR worked out, it was easy to calculate and the timeliness was good.

The warning arithmetic

This research took the LTR as the index, employ TTR warning arithmetic， which defined as the time which takes for the vehicle to reach the critical rollover condition. The Fig.2 is the flow diagram of rollover warning arithmetic, reference 3-DOF rollover model, the current vehicle motion state as the initial conditions, choose step T to calculateTTR, the first time met the index of rollover, took down N, TTR=$N*T$, it demonstrated there was rollover risk, then it send out signal to the active control system. Own to keep timeliness and prevent endless count, set up upper limit time X s, if the vehicle had not rollover within X s, it was safe during that time, while TTR had not reach X, there was rollover risk, the warning time was actual value.

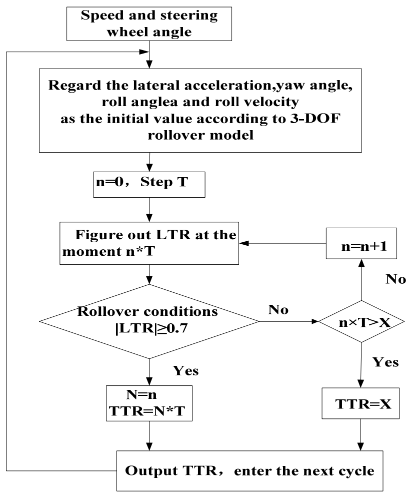

Fig.2 Flow diagram of rollover warning algorithm

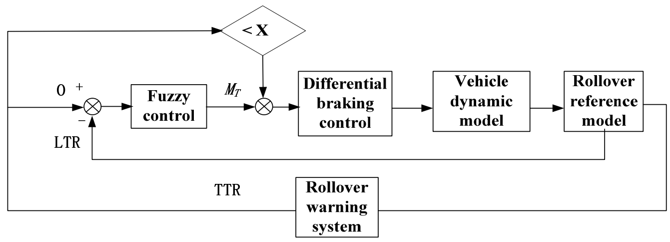

Fig3 Anti-rollover control flow diagram based on warning

Fuzzy differential braking control system

TheAnti-rollover control flow diagram showed in Fig 3.The warning system estimate the TTR according to current motion state while the TTR is smaller than the threshold value(set up 3 seconds),then the trigger controller take active control. The core arithmetic is the fuzzy control arithmetic, from the deviation between LTR and ideal value worked out the yawing moment M_T, applied the differential braking made the anti-rollover control comes true.

The fuzzy controller use two-dimensional controller, the deviation between LTR and ideal value and deviation ratio is input, the Yawing moment is the output. Membership function is Gaussian type, according to theory and experts experience determine the control rules showed in Table.1.The Table.1 is feedback control rule table, the inference system take Mamdani's algorithm, Max-min and centroid defuzzification.

Table.1 Feedback control rule table

M		E						
		NB	NM	NS	ZO	PS	PM	PB
	NB	PB	PB	PB	PM	PS	Z0	ZO
	NM	PB	PB	PM	PS	ZO	ZO	NS
	NS	PB	PM	PM	PS	ZO	NS	NM
EC	ZO	PB	PM	PS	ZO	NS	NM	NB
	PS	PM	PS	ZO	NS	NM	NB	NB
	PM	PS	ZO	ZO	NS	NM	NB	NB
	PB	ZO	ZO	NS	NM	NB	NB	NB

Table.2 The vehicle model parameters

Parameters	unit	value
Full mass	[Kg]	18300
Sprung mass	[Kg]	16800
Moment inertia around X axis	[Kg*m^2]	7695.6
Moment inertia around Z axis	[Kg*m^2]	30782.4
Equivalent lateral stiffness of front axis	[N*rad^{-1}]	150000
Equivalent lateral stiffness of rear axis	[N*rad^{-1}]	350000
Damping factor of suspension	[N*m*s*rad^{-1}]	487000
Wheel base	[m]	5.0
Distance from centroid to front axis	[m]	1.6
Distance from centroid to rear axis	[m]	3.4

Distance from centroid to roll center	[m]	0.8
Front wheel tread	[m]	1.85
Rear wheel tread	[m]	2.10
Steering gear ratio		25

The simulation verification

The wheel sine input simulated in Matlab/Simlink, the Tab.2 is the vehicle model parameters. The initial speed is 100km/h, tire-road friction coefficient is 0.85, amplitude is 200 deg, cycle is 5s,the Fig.4 is the sine input of steering wheel angle,Fig.5 is comparision of yaw rate,Fig.6 is comparision of lateral acceleration,Fig.7 is comparision of roll angle

Fig.5 showed that, yaw rate has reached about 12 deg when there is not control, and then got rollover, while keep within 7deg after control, past that condition success.

Fig.6 showed that lateral acceleration approached 5m/s^2 without control , reach the limit of rollover, while it keeps 2.5m/s^2,always in a safe range.

Fig.7 showed that the roll angle has declined obviously without control, even reach 80 deg and rollover at last, while it got obvious inhibition by fuzzy differential control, within 10 deg, past the experiment success.

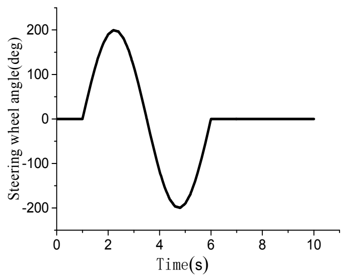

Fig.4 Sine input of steering wheel angle

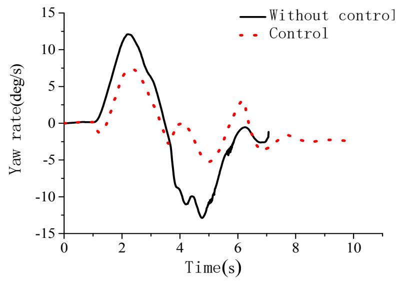

Fig.5 Comparision of yaw rate

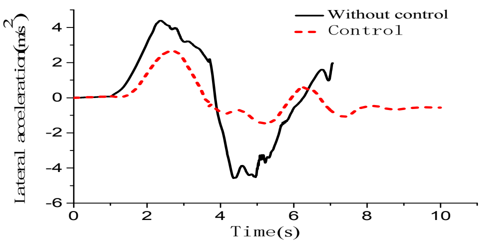

Fig.6 Comparision of lateral acceleration

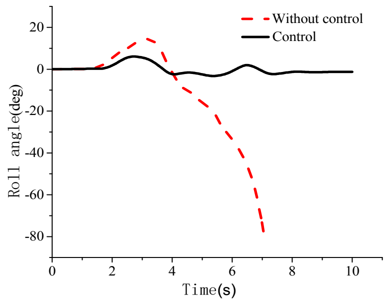

Fig.7 Comparision of roll angle

Conclusion

This article designed a anti-rollover control system based on rollover warning, the warning system depend on 3-DOF reference model, the LTR is index with TTR warning algorithm, apply fuzzy control work out additional yaw moment, and control vehicle state with differential braking. The results in Matlab/simulink showed the anti-rollover control system could greatly improve the rollover and yaw stability of the vehicle, and prevent rollover happen.

Acknowledgement

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