

Multi-Objective Stability Control Algorithm of Heavy Duty Based on EBS

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ABSTRACT

At present, the active safety and stability of heavy vehicles have becoming big concern among the road transportation industry. The purpose of this paper is to specify the research stability and safety of heavy vehicles those set up the accurate and reliable dynamic vehicle reference model and search the method to improve the stability and safety of tractor and semitrailer. A Multi-objective control algorithm was studied to differential braking based on linear quadratic regulator (LQR) control method. Simulation results show that the multi-objective control algorithm can effectively improve the vehicle driving stability and safety.

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INTRODUCTION

With the development of highway, the road transportation industry flourishes based on heavy duty vehicles. The wide application of heavy duty vehicles improve the efficiency of road transportation and reduce the cost of goods delivery. The stability of heavy duty vehicle and semitrailer often cause occurrence of rollover, swing, and jackknife, because the vehicles have a higher gravity-center, larger loads and relatively narrow tread in comparison with the height of vehicle. For years the accidents of heavy vehicles are in a status of high frequency and how to solve the problem of stability and safety of heavy duty vehicles have become a key factor in road transportation industry [1], [2]. In a rollover accident, the tractor and semitrailer of heavy vehicles rotate around each other longitudinal axis - typically 90 degrees or more [3]. By reviewing the previous research, the stability of tractor and semitrailer has been put into categories that yaw stability and roll stability control algorithms have been studied [4], [5].

A multi-objective braking force distribution algorithm is proposed to improve the safety and stability of tractor and semitrailer in this paper, in which control variables include yaw rate, lateral acceleration, hitch angle and hitch rate. A six-axle plane reference dynamic model of tractor and semitrailer is built, which number of axles is equal to actual heavy duty vehicle. The precision of this model is verified through the actual heavy vehicle model in the software of TruckSim®. Because of tractor and semitrailer are linked with the fifth wheel flexibly, the number of freedom for dynamic model is more than that of bus and tractor. Because there are related between the yaw rate and lateral acceleration of tractor and

trailer, so it used tractor's parameters when producing optimum braking moment with LQR method. At last, the control strategy is simulated and verified with the typical condition.

TRACTOR AND SEMITRAILER MODEL

The body of the paper should include detailed and structured description of the work performed, including (as appropriate) methodology, assumptions, hardware, observations, analysis, and a comparison of results with prior work. The information presented must be self-contained (in the sense that the reader is not assumed to have read prior papers) and provide an appropriate level of detail for the intended audience. Define all terms at first usage and apply them consistently.

The body section is not entitled "Body". Rather it comprises multiple sections and subsections titled using topical headings in a four-level structure. Template styles [Head1] through [Head4] are used to tag and format titles of the different levels. No specific heading titles are mandated, but common examples include Methods, Results, and Discussion. The [Normal] style tag is used for paragraph text. Figures, tables, and equations fall under the body section. Found in this template are examples of a figure, a table, and equations (which must be kept to 3.5" wide).

In the road transportation industry, the six-axle tractor and semitrailer is widely applied because of its high efficiency. First of all, a six-axle plane reference dynamic model was built that mainly state parameters included yaw angle, yaw rate, lateral acceleration, hitch angle and hitch rate of tractor and semitrailer [6].

The equation of lateral force is calculated from

$$(m_1 + m_2)\dot{v} + m_2(a - c - d)\dot{r} - m_2\ddot{q} = \frac{-\sum_{i=1}^6 C_i}{u}v + \frac{\sum_{i=1}^6 (l_i C_i) - (m_1 + m_2)u^2}{u}r + \frac{\sum_{j=i+3}^3 (f_j C_j)}{u}\dot{q} + \sum_{i=4}^6 C_i q + C_1 \delta \quad (1)$$

Where m_1 is tractor mass, m_2 is trailer mass, v is lateral velocity of tractor, a is the distance from front axle to mass center of tractor, c is the distance from front axle to hitch (the fifth wheel), d is the distance from hitch to mass center of trailer, r is yaw rate of tractor, q is hitch angle, C_i ($i = 1, \dots, 6$) is cornering stiffness of every axis, u is longitudinal velocity of tractor, f_1 is the distance from hitch to fourth axle, f_2 is the distance from hitch to fifth axle, f_3 is the distance from hitch to sixth axle, δ is front wheel angle.

The moment balance equation of tractor mass center is calculated from

$$m_2(a - c - d)\dot{v} + [J_1 + J_2 + m_2(c - a + d)^2]\dot{r} + [J_2 + m_2(c - a + d)]\ddot{q} = \frac{\sum_{i=1}^6 (l_i C_i)}{u}v + \frac{-\sum_{i=1}^6 (l_i C_i) + l_7 u^2 m_2}{u}r + \frac{-\sum_{j=i+3}^3 (f_j l_j C_j)}{u}\dot{q} + \left(-\sum_{i=4}^6 (l_i C_i)\right)q + a C_1 \delta \quad (2)$$

Where J_1 is tractor rotational inertia, J_2 is trailer rotational inertia. The hitch moment balance equation of trailer is calculated from

$$(-m_2 d)\dot{v} + [J_2 + m_2 d(c - a + d)]\dot{r} + (J_2 + m_2 d^2)\ddot{q} = \frac{\sum_{j=i+3}^3 (f_j C_j)}{u}v + \frac{-\sum_{i=1}^6 (f_i l_i C_j) + d m_2 u^2}{u}r + \frac{-\sum_{j=i+3}^3 (f_i^2 C_j)}{u}\dot{q} + \left(-\sum_{j=i+3}^3 (f_i C_j)\right)q \quad (3)$$

$$\begin{cases} l_1 = -a \\ l_2 = b_1 - a \\ l_3 = b_2 - a \\ l_4 = f_1 + c - a \\ l_5 = f_2 + c - a \\ l_6 = f_3 + c - a \\ l_7 = c + d - a \end{cases} \quad (4)$$

The equation for (1), (2), (3), (4) can be written for state propagation as

Where

$$M_6 = \begin{bmatrix} m_1 + m_2 & (a - c - d)m_2 & -dm_2 & 0 \\ (a - c - d)m_2 & J_1 + J_2 + (a - c - d)^2 m_2 & J_2 - d(a - c - d)m_2 & 0 \\ -dm_2 & J_2 - d(a - c - d)m_2 & J_2 + d^2 m_2 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix},$$

$$K_6 = \frac{1}{u} \begin{bmatrix} -\sum_{i=1}^6 C_i & \sum_{i=1}^6 (l_i C_i) - (m_1 + m_2)u^2 & \sum_{j=i+3}^3 (f_j C_j) & u \sum_{i=4}^6 C_i \\ \sum_{i=1}^6 (l_i C_i) & \sum_{i=1}^6 (l_i C_i) + l_7 m_2 u^2 & -\sum_{j=i+3}^3 (f_j l_j C_j) & -u \sum_{i=1}^6 (l_i C_i) \\ \sum_{j=i+3}^3 (f_j C_j) & -\sum_{j=i+3}^3 (f_j l_j C_j) + d m_2 u^2 & -\sum_{j=i+3}^3 (f_i^2 C_j) & -u \sum_{j=i+3}^3 (f_i C_j) \\ 0 & 0 & u & 0 \end{bmatrix}$$

$$x = \begin{bmatrix} v \\ r \\ q \\ \dot{q} \end{bmatrix}, \quad B_6 = \begin{bmatrix} C_1 \\ a C_1 \\ 0 \\ 0 \end{bmatrix}$$

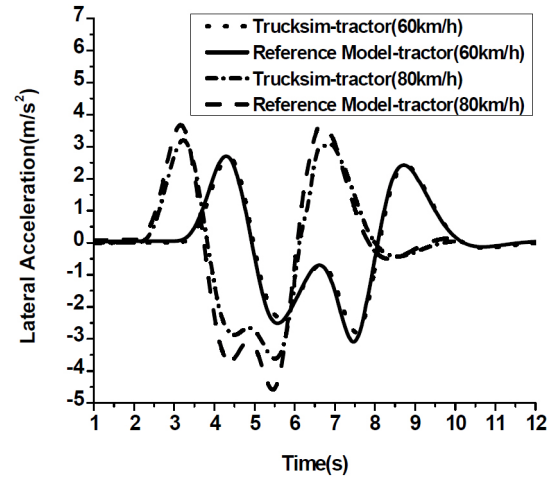


Figure 1. Lateral acceleration of tractor.

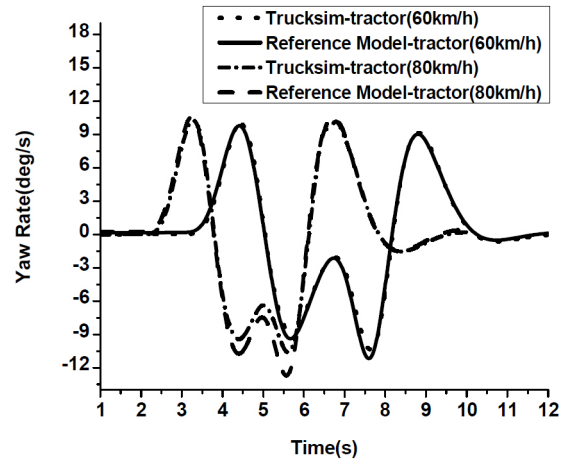


Figure 2. Yaw rate of tractor.

In order to validate the effect of six-axis dynamic reference model, TruckSim® software was used to test the precision of reference model in a lane change condition. The simulation experiments include that vehicle speed is 60 km/h and 80 km/h and road friction coefficient is 0.7. From figure 1, figure 2,