

Enhancement of Yaw and Roll Stability for Trucks by Estimating Payload Conditions

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ABSTRACT

Electronic stability control (ESC) is being incorporated as a standard feature in almost all passenger cars since it is highly effective in reducing road accidents. Moreover, many commercial vehicles can be equipped with ESC, which includes roll stability control. ESC determines vehicle stability on the basis of the driver's operation, vehicle behavior, and preset control parameters. When the vehicle stability is likely to be lost, control intervenes to stabilize the vehicle. The characteristics of commercial vehicles affect the ESC parameters and vary significantly with the payload (e.g., weight and height of the cargo and the loading state). Therefore, the control parameters need to be adjusted according to the loading conditions to enhance vehicle stability and avoid unnecessary control intervention.

We have developed an ESC that improves the yaw and roll stability of trucks. For this development, accurate evaluation of the payload states is important. The payload states, in turn, are determined by estimating the vehicle mass accurately. Essentially, the vehicle mass is estimated on the basis of the driving force and the longitudinal acceleration when a vehicle is accelerating. The driving force is calculated from the engine speed and the throttle position, while the longitudinal acceleration is detected by sensors. However, the measured driving force and longitudinal acceleration include errors attributable to the aerodynamic drag of the vehicle body, rolling resistance of the tires, inertia force and friction loss of the power train, and zero drift of the sensors. An algorithm for estimating the vehicle mass has been developed to compensate for these errors. In this algorithm, the state variables when the gearshift is in the neutral position (i.e., when the vehicle is coasting) and in another position (i.e., when the vehicle is accelerating) are compared in order to nullify the errors. In this paper, we describe a vehicle mass estimation algorithm that adjusts the control parameters according to the payload conditions and discuss vehicle tests that demonstrate the effectiveness of ESC based on this estimation.

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INTRODUCTION

Electronic stability control (ESC) is a system for enhancing vehicle stability, and it assists the driver in critical driving situations (for instance, slippery roads). With the use of ESC, traffic accidents are effectively prevented since this system helps in stabilizing the vehicle and preventing skidding. Many research institutes and automobile manufacturers have conducted statistical investigations on the effectiveness of ESC, especially the effectiveness of ESC in mitigating traffic accidents. The investigation results indicate that ESC can mitigate serious accidents, which occur when the driver finds it impossible to control the vehicle, by at least 30% (Ref. [1]). For this reason, ESC has gained immense popularity, and its use in vehicles has been recognized to be mandatory (e.g., Ref. [2]). The United States requires that all 2012 passenger cars weighing less than 10,000 lbs. (4.5 tons) be equipped with ESC systems. The European Union has

confirmed that ESC would be introduced in all new passenger and commercial vehicle models sold from the year 2012, and that new vehicles would be mandatorily equipped with ESC by 2014. Similarly, in Japan, ESC will be compulsorily incorporated in all new vehicle models from the year 2012 and all passenger cars manufactured from 2014 onwards would be equipped with ESC.

ESC for commercial vehicles and sport utility vehicles (SUVs) has been developed with due consideration of the effects of roll stabilization (Refs. [3], [4], and [5]). Since the center of gravity (c.g.) of commercial vehicles and SUVs is at a greater height from the ground than is the c.g. of passenger cars, ESC must ensure stability of roll behavior (attitude stability of a vehicle) as well as yaw motion (directional stability of a vehicle). Moreover, the vehicle characteristics (vehicle mass, c.g. position, etc.) vary significantly with the payload, and this dependence is particularly true for

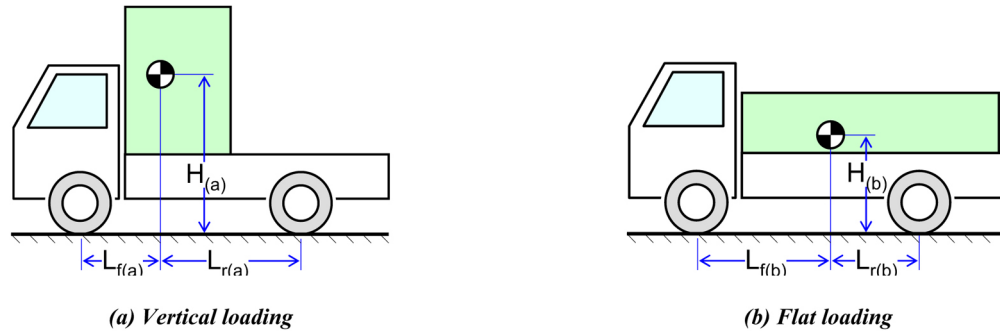


Figure 1. Change in the location of the center of gravity with differences in the payload

commercial vehicles. Since ESC determines the stability of the vehicle on the basis of the steering operation performed by the driver, vehicle behavior, and control parameters corresponding to the vehicle characteristics, it is necessary to adjust these parameters for commercial vehicles according to the payload conditions. In this paper, we describe an algorithm for estimating the vehicle mass and thus obtain information regarding the payload conditions. We also describe an ESC in which the control parameters for trucks are adjusted according to the payload conditions.

VARIATION IN VEHICLE PARAMETERS WITH PAYLOAD CONDITIONS

The characteristics of commercial vehicles vary more significantly with the payload than do the characteristics of passenger cars; this is because the payload capacity is considerably higher in the former case. For example, Liebmenn et al. have reported that the differences in the vehicle mass, vertical position of the c.g., and longitudinal position of the c.g. between the unloaded and loaded states are 39%, 5%, and 5% for passenger cars, respectively. The abovementioned differences for light commercial vehicles are 95%, 25%, and 53%, respectively (Ref. [3]). Commercial vehicles whose characteristics vary considerably in different loading states must be controlled as per the payload conditions since the control thresholds and degree of control should be determined on the basis of the vehicle characteristics. If the control parameters are fixed at values suitable for the unloaded state, vehicle stability might be lost when the vehicle is loaded to its capacity. On the contrary, there might be excessive intervention by ESC when the vehicle is in the unloaded state if the control parameters are fixed for the fully loaded state (i.e., on the basis of the gross vehicle weight, GVW).

Furthermore, the vehicle characteristics change with the loading state even if the payload remains the same. The c.g. shifts to a higher position and moves closer to the front axle when the payload is highly stacked, as shown in Figure 1(a). In this case, the vehicle shows increased roll tendency since the roll moment increases with the increased distance of the

c.g. from the ground surface. On the other hand, the c.g. is at a relatively lower position and is closer to the rear axle in the case of flat loading, as shown in Figure 1(b). In this case, the vehicle shows oversteer tendency since the yaw moment increases with the increased distance between the c.g. and the front axle.

Many research and development activities have been conducted for accurate estimation of the c.g. position of a vehicle (Refs. [6] and [7]). However, a roll-motion sensor (used for detecting the roll angle and/or speed), a load sensor for each wheel, and so on are necessary for accurate estimation of the c.g. position with robustness. We have attempted to optimize the ESC on the basis of the change in the vehicle characteristics by using the sensors already equipped in the vehicle. Our idea is to adjust the control thresholds on the basis of the correctly estimated vehicle mass with the payload, for nullifying the influence of the payload. Figure 2 shows an example of the adjustment characteristic (a calculation map) of the control thresholds for a certain truck. This adjustment characteristic is experimentally obtained. Through vehicle tests, we have verified that the control thresholds can be adjusted to eliminate the trade-off between vehicle stability and unnecessary intervention of the ESC while the payload conditions change, by using the experimentally tuned adjustment characteristic and the accurately estimated vehicle mass.

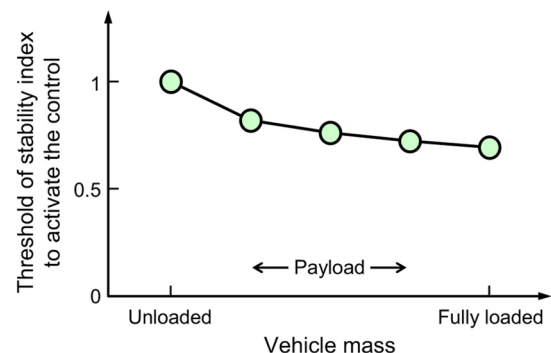


Figure 2. Threshold adjustment to reconcile vehicle stabilization with unnecessary control intervention

ESTIMATION OF VEHICLE MASS ON THE BASIS OF DRIVING FORCE AND LONGITUDINAL ACCELERATION

Generally, the vehicle mass is calculated by using the relationship between force and acceleration (Ref. [8]). Specifically, the vehicle mass is calculated on the basis of the driving force $F_x(n)$ and the longitudinal acceleration $G_x(n)$, as shown in Equation (1):

$$M_{veh} = \frac{F_x(n)}{G_x(n)} \quad (1)$$

Here, “n” in parenthesis indicates the gearshift position of the transmission. For example, “1” indicates the first position (i.e., the lowest gear). $F_x(n)$ is obtained from the engine power, which in turn is calculated on the basis of the throttle position θ_{th} and the engine speed N_e . $G_x(n)$ is detected by an acceleration sensor. Figure 3 shows the value of the vehicle mass M_{veh} calculated using Equation (1), when the vehicle is accelerated from the stopped state. The result shows that M_{veh} cannot be estimated accurately using this equation.

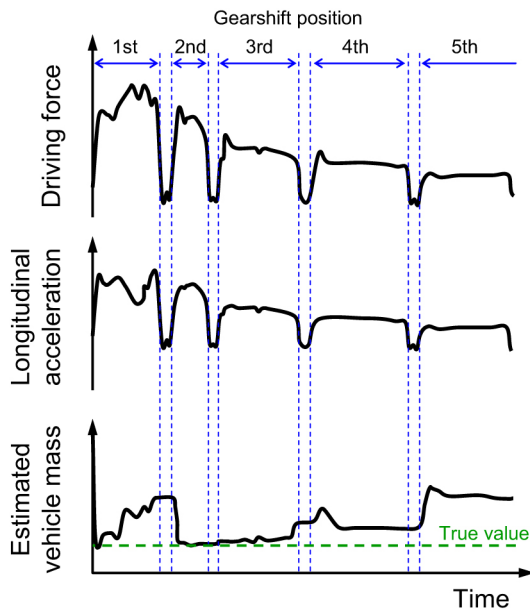


Figure 3. Error in the estimation of vehicle mass on the basis of driving force and longitudinal acceleration

In this section, errors encountered in estimating the vehicle mass are discussed. Although M_{veh} is estimated on the basis of $F_x(n)$ and $G_x(n)$, these state variables include errors. On the basis of experimental analysis, the parameters that contribute to engine power consumption at a certain gearshift position are determined; the details of these are shown in figure 4. In addition to F_x , which accelerates the

vehicle, the rolling resistance F_{R0} of the tires, aerodynamic drag F_L of the vehicle body, and friction loss F_{Fr} and inertia force F_{In} of the power train system (i.e., engine, transmission, and drive line) contribute to engine power consumption. Among these components, F_{R0} , F_L , and F_{Fr} vary with the running state of the vehicle, environmental conditions, aging of the vehicle components, etc.

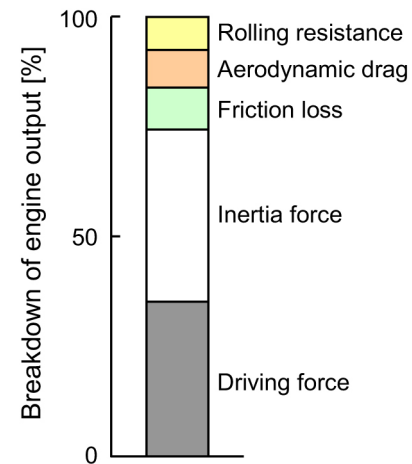


Figure 4. Details of the components that contribute to engine power consumption

Figure 5 shows the errors included in the output signal of the longitudinal acceleration sensor, as determined by analyzing experimental data. Since $G_x(n)$ is not very high when the vehicle starts, zero drift greatly influences the estimation accuracy of the sensor. Moreover, since the longitudinal acceleration sensor is attached to the vehicle body, the sensor is influenced by the vehicle's pitching motion.

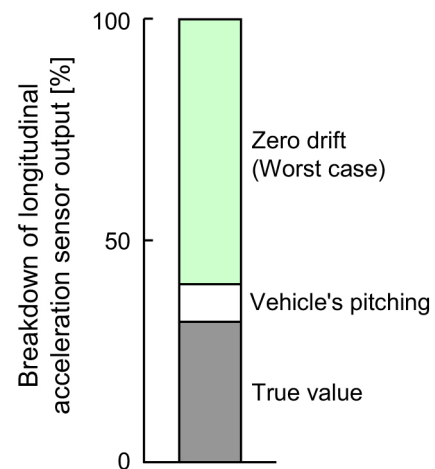


Figure 5. Errors in the output of the longitudinal acceleration sensor