

STABILITY AUGUMENTATION SYSTEM FOR THE HEAVY DUTY COMMERCIAL VEHICLES - ESTIMATION OF THE GRAVITY POSITION WITH AR METHOD AND APPLICATION FOR ANTI-ROLLOVER

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ABSTRACT

The increasing requirement for vehicle safety enforces us to do further investigation research for the stability control system of commercial heavy duty vehicles. About 50% of the these accidents are caused by vehicle spin-out and rollover. Hence, advanced stability control for heavy duty vehicle needs to be implemented. In this paper, the vehicle gravity position is estimated in using Auto-Regressive (AR) method since the commercial vehicle dynamic characteristics is changeable due to its unspecified load. And the rollover behavior is predicted by both the gravity position and the rolling condition such as rolling behavior. Thus rollover preventing system is proposed.

1. INTRODUCTION

Based on the investigation, vehicle spin-out and rollover take up the 50% of the serious heavy duty vehicle accidents. When the spin control technique is developing for passenger cars, according to Advanced Safety Vehicle, it is necessary to develop stability control techniques for commercial vehicle in these conditions. One of the important problem is to capture the gravity position for which is affected by loading goods status. Hereafter, based on the vehicle transfer function measurement, the gravity height is estimated by AR method. Then according to the gravity estimation information, the wheel brake force is controlled in order to prevent rollover behavior.

2. PHENOMENAL CONFIRMATION

Vehicle gravity position and height are changeable with the unloaded or loading status. Therefore, it is very important to understand the kinetic characteristics such as the gravity position and height, and so forth. Rolling feature is changed with the variance of gravity height

during lane change, as shown in Fig. 1. If the gravity is higher, the vehicle roll rate is larger and phase delay happens. Generally, truck driver can feel the roll motion according to different loading status and can take measure to guarantee the safe driving.

Difference of the rolling behavior caused by the gravity center height at lane change condition.

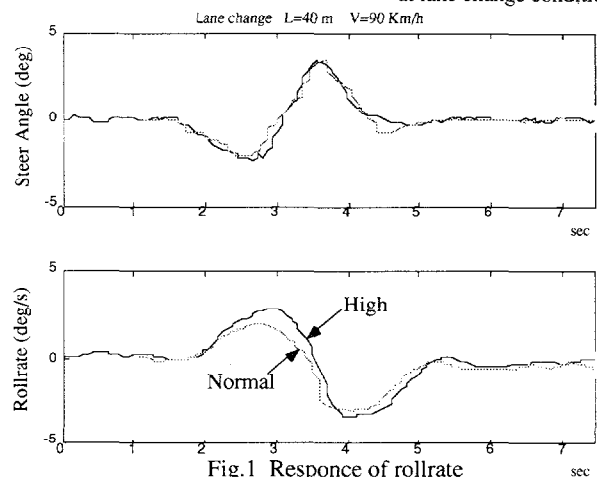


Fig.1 Responce of rollrate

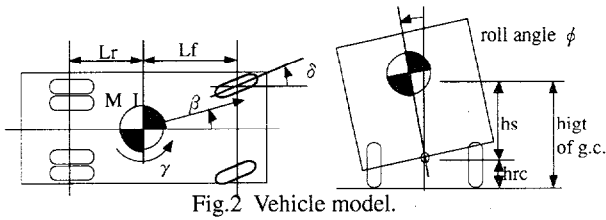
3. GRAVITY POSITION ESTIMATION

3.1 Estimation Consideration

In consideration of the gravity position, the estimation method is investigated for gravity height. In this paper, based on kinetics model with roll motion freedom, the transfer function from steering input to roll output can be estimated. Through the coefficients comparison with experimental transfer function data by AR method, we can get the gravity height.

3.2 Theoretical Equations

In order to obtain the transfer function from steering input to roll output, the kinetics model is described by the coordinate system fixed on vehicle (Fig.2). The 3 DOF model with roll, lateral slip angle and yaw is concerned.



The all equations are written as the followings.

$$s\dot{x} = A'x + Bu$$

$$A' = M^{-1}A''$$

$$M = \begin{pmatrix} MV & 0 & -Mhs & 0 \\ 0 & I & 0 & 0 \\ -MhsV & 0 & I_\phi & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

$$A'' = \begin{pmatrix} 2(K_f + K_r) & \frac{2(K_f L_f - K_r L_r)}{V} - MV & 0 & -2(K_f \alpha_f + K_r \alpha_r) \\ 2(K_f L_f - K_r L_r) & \frac{2(K_f L_f^2 + K_r L_r^2)}{V} & 0 & -2(K_f L_f \alpha_f - K_r L_r \alpha_r) \\ 0 & MhsV & -C_\phi & -K_\phi \\ 0 & 0 & 1 & 0 \end{pmatrix}$$

$$B = M^{-1}B'$$

$$B' = (-2K_f \quad -2K_f L_f \quad 0 \quad 0)^T$$

$$x = (\beta \quad \gamma \quad \phi \quad \dot{\phi})^T$$

$$\phi(s) = Cx \cdot \delta(s)$$

Concerning roll motion, expanding the transfer function of steering angle-roll:

$$\frac{\phi(s)}{\delta(s)} = Cx = CA^{-1}B \quad \text{----- [1]}$$

$$\therefore A = sE - A'$$

E: Identify

det(A): determinant of A

$$C = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 1 \end{pmatrix}$$

as followings[1]

$$\frac{\phi(s)}{\delta(s)} = \frac{e_2 s^2 + e_1 s + e_0}{\det(A)} \quad \text{----- [2]}$$

3.3 Transfer Function Extracted by AR method

Based on the input and output experimental data of the test vehicle, AR model is expressed as:

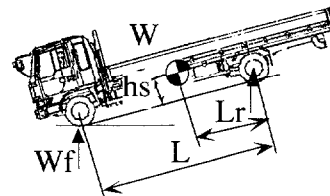
$$a(q)y(t) = b(q)u(t - nk) + e(t)$$

This description is transformed to continuous system. As described above, the obtained transfer function order is same as that of Eq. [2]. Therefore, the power item of the polynomial of transfer function is corresponding to the correlative item. If taking the coefficient of s^2 item as e_2 , gravity hs is the function of e_2 and other vehicle element. In other words, if we have the coefficient of transfer function and other vehicle element, the gravity height can be calculated as:

$$hs = F(e_2) = \frac{K}{MsV} \frac{\frac{2}{V} K_f K_r l^2 - VM(K_f l_f - K_r l_r)}{e_2 - 2K_r \{2K_r l_r \alpha_r - K_f l_f (\alpha_f + \alpha_r)\}}$$

3.4 Experimental Gravity Estimation and Test vehicle

Based on Security Guarantee Standard, the static gravity measurement method is shown in Fig. 8.



$$hs = \frac{W \cdot Lr - Wf \cdot L}{W \tan \alpha}$$

Fig.3 Hight of gravity center

Here the middle-sized truck is loaded with two conditions. One is lower flat concrete load and the other is the higher load status, and both the gravity height measurement, as well as the gravity height measurement of unloaded condition are taken as the true values. According to these conditions, the steering angle, roll rate and vehicle velocity are measured on a common road conditions.

3.5 Data Processing

In vehicle riding, comparing with yaw rate, roll rate is easily to be affected by the cant road surface or rugged road surface when the input is steering angle. As seen in Fig. 4, roll angel has a low coherence with the steering angle input.

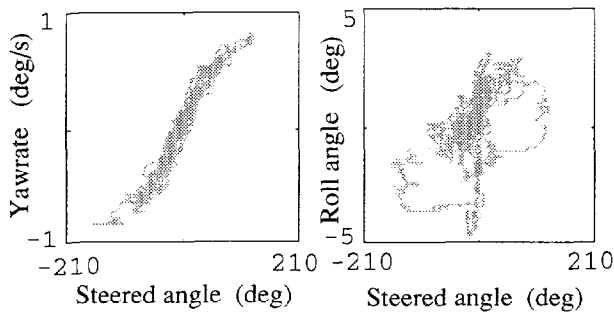


Fig.4 Responce of Yawrate and Roll angle

This is why the acquainted data can not be used directly in estimation. Therefore, the roll response is appropriately extracted in using the continuous algorithm for data pre-processing (Fig. 5), and taking the filtered data to input to the gravity calculation system.

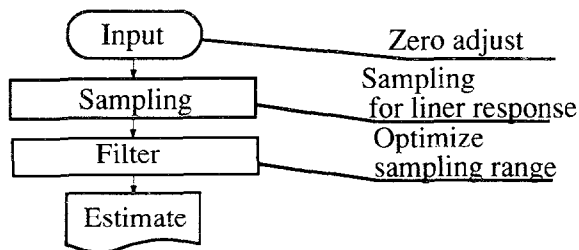


Fig.5 Data processing

All accumulated mean values are started from zero in order to prevent the zero-drifting measurement signals. Moreover, reliable roll response is pursued by taking a certain value of steering input as the trigger signal then recording the sample signals.

Roll rate is sensitive to lateral motion caused by uneven road surface in high frequency range. However, in low frequency range, when roll is integrated as the road cant and vehicle roll rate, integral error exists. In order to prevent roll angle calculation from these influences, band-pass filter is applied for ordinary frequency range. And this is helpful in enhancing measurement sensitivity.

After these process, according to AR method, single-input and single-output transfer function is determined then gravity height can be calculated as described in above section 3.2.

4. ESTIMATION RESULTS

4.1 Premise Condition of Gravity Estimation

The following is the analysis results. Data are collected from the test-course (Fig. 1) and from town road (Fig. 6). The estimation results in using these data are shown in Fig. 7.

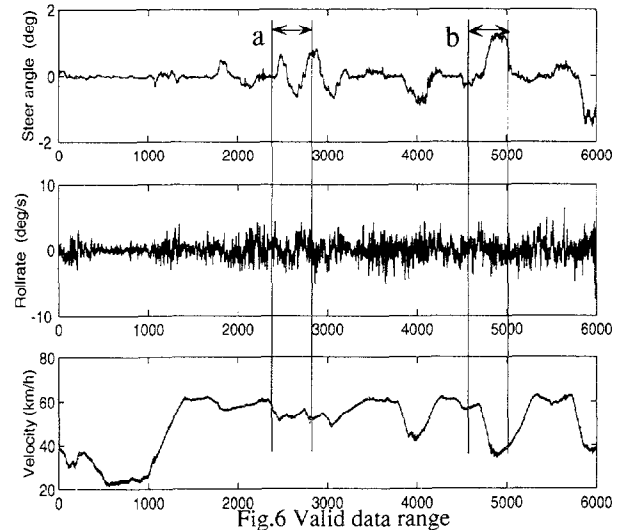


Fig.6 Valid data range

The areas indicated by the arrows in Fig. 6 are used to construct the transfer function. It is very possible to perform the estimation as the coherence between steering input and roll rate located in a higher s/n ratio area.

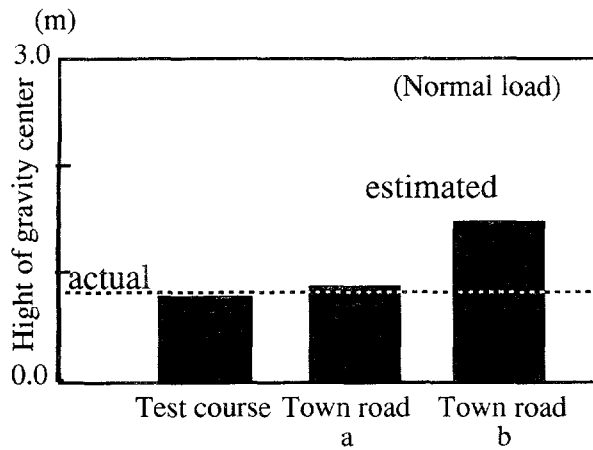


Fig.7 Estimated value

On the other hand, when the input-output are not sufficient or the speed change rate is large, the estimation is different from the true value. Therefore, higher S/N ratio and lower speed change rate is the necessary premise for the estimation.

4.2 Loading Condition and Gravity Height Estimation

With the premise condition of 5.1, when the loading condition is changed and the gravity height is calculated (Fig. 8). The gravity height is in accordant to the trend of the loading status.

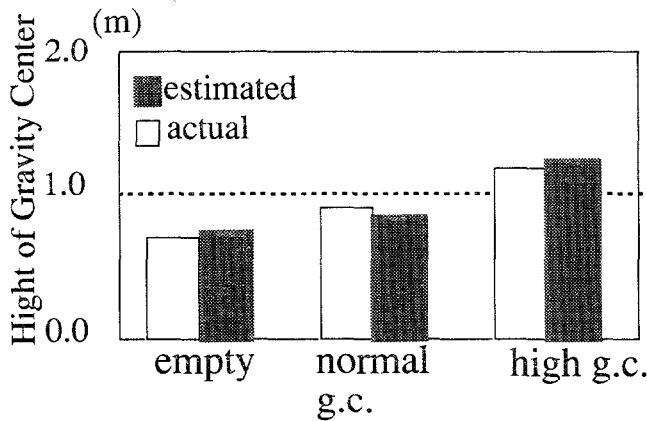


Fig.8 Estimated value

5. APPLICATION TO LATERAL SPIN CONSTRAINT CONTROL

The compensation control for course-out is shown in Fig. 9. The basic theory is founded on the observer

estimation for side slip angle, whose inputs are steering angle, yaw rate and gravity speed; and the observer is composed of vehicle specifications and tire characteristics. The systematic characteristics of tire are arranged by Takahasi, et al. According to the side slip states, wheel brake force is controlled to decrease the rollover and this is well known for side slip control of passenger cars. In addition to this control strategy, rollover prevention control should be applied in commercial vehicle control and the consideration is demonstrated as follows.

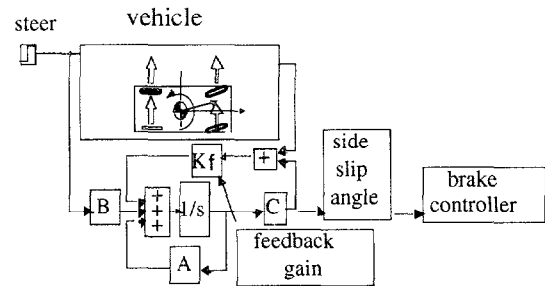


Fig9 Observer

5.1 Rollover Detection

Same as the side slip state estimation, rolling state can be sketched as the quadrant plane (Fig. 10) according to roll and its angle speed. The rolling behavior located in the 1st and 3rd quadrant tends to be divergent and it is possible to estimate the stability in using gravity height information. The result of stability estimation makes wheel brake act appropriately and prevent rollover behavior.

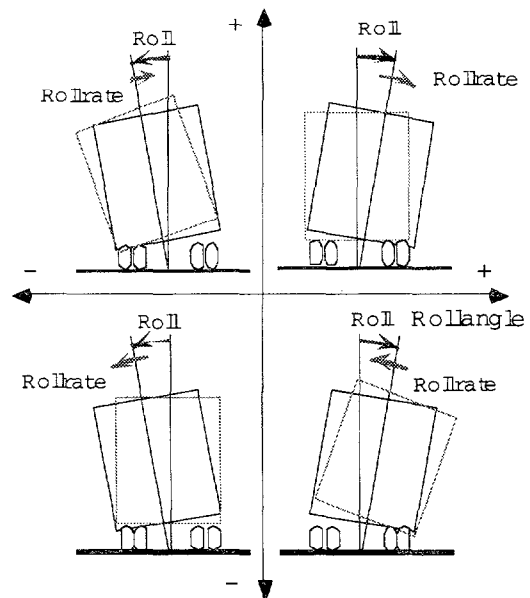


Fig.10 Analysis for rolling behavior

5.2 Application of Rollover Prevention

An experimental result for rollover prevention is shown in Fig. 11. This is the measurement when the test vehicle is passing a J-turn.

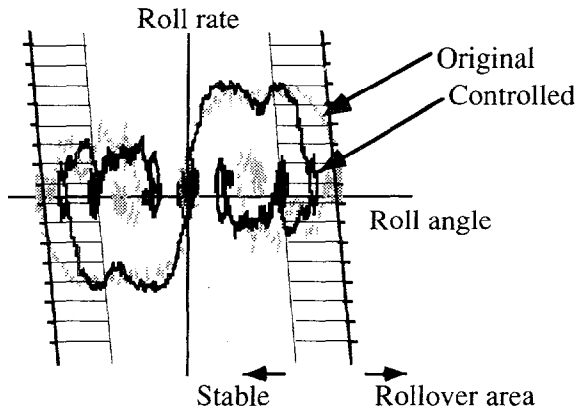


Fig11 Experimental result for anti-rollover protection

When the rollover behavior is over a certain threshold by inspecting the gravity height, the system makes each wheel brake work then reduce the rolling motion quickly. When the maximum roll angle is compared, the roll angle of the controlled vehicle is 2 degree smaller than that of uncontrolled vehicle, and the vehicle can safely pass the curve without getting over the lateral spin criteria(Fig.12).

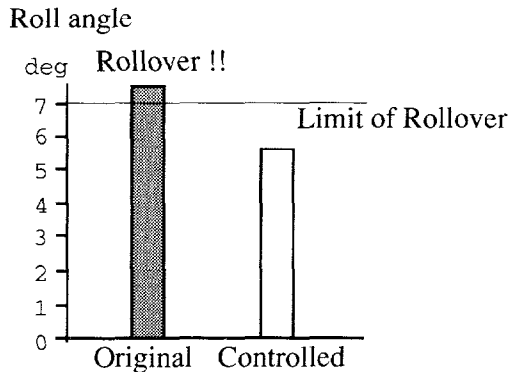


Fig12 Maximum roll angle at J turn testing

6. CONCLUSIONS AND FUTURE WORK

Through the comparison of transfer function coefficients between the kinetic model and AR estimation model coming from experiment data, the gravity height estimation is performed. As the results of our study, (1) vehicle gravity height can be precisely estimated; and (2) the gravity height can be decided according to the loading status, e.g., flat loading or higher loading status. As the application, the lateral spin prevention control in using the information of vehicle roll and roll rate is testified and good result is achieved.

As the future work, we need to guarantee the system reliability for practical application.

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