Vehicle Control Strategy on High Speed Obstacle Avoidance under Emergency

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Abstract. The most important task for the driver in a vehicle running at high speed is to bypass the obstacle under emergency because of insufficient vehicle-to-vehicle distance. A vehicle dynamics control strategy was developed to prevent vehicles from spinning and drifting out on high speed obstacle avoidance under emergency. With vehicle dynamics control system, counter braking is applied at individual wheels as needed until steering control and vehicle stability are regained, i.e. the vehicle can pass by the obstacle. On the other hand, vehicle dynamics control system may increase the vehicle roll angle, or even deteriorate on-road rollover events. An anti-rollover control system was introduced in this paper to prevent vehicle from rollover. The simulation results showed that with this improved control system, the vehicle can afford nice manoeuvrability and passenger comfortability.

Keywords: Vehicle Dynamic Control, Anti-rollover Control, Obstacle Avoidance, Electronic Braking System.

1 Introduction

High speed obstacle avoidance technology under emergency helps to reduce the risk of rear-end collisions and to prevent a rollover accident from ever happening. A vehicle dynamics control (VDC) is an active safety system that reduces the risk of a driver losing control of the vehicle on high speed obstacle avoidance.

Also known as electronic stability programs (ESP), VDC builds upon features such as anti-lock braking systems (ABS) and traction control to stabilize the vehicle when it changes direction from that intended by the driver.

Fig. 1 shows the risk situation that the front vehicle sudden stop will cause a rear-end collision because of the high speed and insufficient vehicle-to-vehicle distance. The rear auto must perform a lane change maneuver to avoid a crash. Under emergency, most drivers will steer the steer wheel sharply, unless he or she is stunned by the suddenness of the danger. Due to the sharp heavy steer on the vehicle, if without any control system, it’s impossible for the driver to achieve that. There are only two results left to the driver: rear-end collision or rollover.

In this paper will present and discuss two control systems, vehicle dynamics control system and anti-rollover control system (ARC). The two systems play different roles in vehicle high speed obstacle avoidance under emergency.

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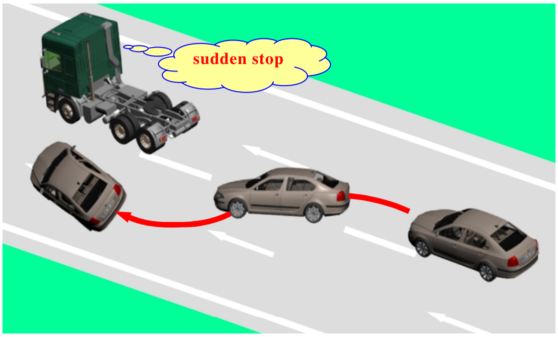

Fig. 1. Obstacle avoidance under emergency

2 Vehicle Dynamics Control

Vehicle dynamics control system that prevent vehicles from spinning, drifting out and rolling over have been developed and recently commercialized by several automotive manufacturers.

Vehicle dynamics control essentially makes ABS a full-time expert back seat driver that's constantly monitoring how the vehicle is responding to the driver and road conditions. If the vehicle is understeering, it is trying to continue straight ahead and the driver needs to apply more steering effect in order to get round the bend. If oversteer is occurring, the rear of the vehicle tends to move outwards and effectively reduce the radius of turn. It is a condition that worsens as oversteer continues.

To better control vehicle dynamics under all driving conditions, the vehicle dynamics control system needs some additional inputs against ABS. This includes a steering angle sensor to monitor the driver’s steering inputs, a yaw sensor to detect changes in vehicle momentum that might cause the vehicle to spin out, oversteer or understeer, the system configuration is shown in fig. 2.

When the driver steers the vehicle, the steering angle sensor keeps the vehicle dynamics control module informed about where the driver is aiming the vehicle and the rate at which the steering wheel is being turned (fast or slow). At the same time, the vehicle dynamics control module looks at the inputs from its wheel speed sensors to

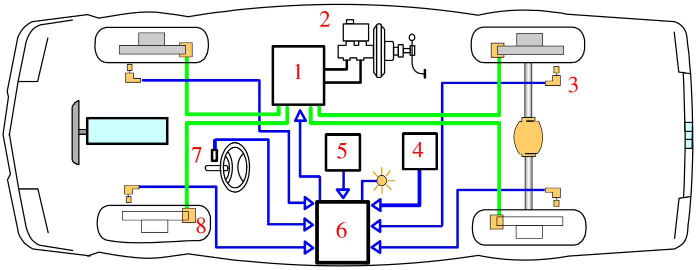

Fig. 2. System configuration of vehicle dynamics control 1-pressure regulator; 2-master cylinder; 3-wheel speed sensor; 4-yaw sensor; 5-roll sensor; 6-ECU; 7-steering angle sensor;8-brake cylinder

determine if there are any differences in the rotational speeds of the right and left front and rear wheels. Turning a corner causes the inside wheel to rotate at a somewhat slower rate than the outside wheel.

3 Vehicle Dynamics Analysis

A vehicle may be regarded as a control system upon which various inputs are imposed. During a turning maneuver, the steer angle induced by the driver can be considered as an input to the system, and the motion variables of the vehicle, such as yaw rate, lateral acceleration, and curvature, may be regarded as outputs.

Yaw rate gain is an often used parameter for comparing the steering response of road vehicles. It is defined as the ratio of the steady-state yaw rate to the steer angle. Yaw rate ω_r of the vehicle under steady-state conditions is the ratio of the forward speed u to the turning radius R. The yaw rate gain G_{yaw} is given by

$$G_{yaw} = \left.\frac{\omega_r}{\delta}\right)_s = \frac{u}{L + Ku^2 / g} \tag{1}$$

where δ is the front wheel turning angle,

L is the wheelbase of the vehicle,
K is the understeer coefficient,
g is the acceleration of gravity.

Equation (1) gives the yaw rate gain with respect to the steer angle of the front wheel. If the yaw rate gain with respect to the steering wheel angle is desired, the value obtained from Eq. 1 should be divided by the steering gear ratio.

For a neutral steer vehicle, the understeer coefficient is zero; the yaw rate gain increases linearly with an increase of forward speed. For an understeer vehicle, the understeer coefficient K is positive. The yaw rate gain first increase with an increase of forward speed, and reaches a maximum at a particular speed.

For an oversteer vehicle, the understeer coefficient K is negative; the yaw rate gain increases with the forward speed at an increasing rate. Since K is negative, at a particular speed, the denominator of Eq. (1) is zero, and the yaw rate gain approaches infinity.

The results of the above analysis indicate that from the point of view of handling response to steering input, an oversteer vehicle is more sensitive than a neutral steer one. A neutral steer configuration can provide maximum cornering performance.

If the wheelbase is small compared to the steer radius and the slip angle is small, then the yaw rate of neutral steer vehicle ω_0 can be obtained from Eq. (1):

$$\omega_0 = \frac{u_0}{L}\delta_0 \tag{2}$$

The object of vehicle yaw stability control is to keep the yaw rate ω as close to neutral yaw rate ω_0 as possible by applying braking at individual wheels as needed.

4 Vehicle Dynamics Control Strategy

We employ the linear bicycle model to generate the reference vehicle behavior, such as yaw rate of neutral steer. The difference of yaw rate between the reference model and the multi-body model is considered as control signal to the vehicle multi-body model. The vehicle multi-body model is shown in fig. 3, which was built in ADAMS/CAR (Automatic Dynamic Analysis of Mechanical Systems).

In order to verify the vehicle dynamics control strategy, we performed a dynamic analysis using ADAMS/CAR and Simulink. The full vehicle was assembled in ADAMS/CAR, as shown in fig.3, and the control system was completed in Simulink, as shown in fig. 5.

Vehicle dynamics control system can actively brake individual wheels in an effort to improve vehicle stability or handling near and at the limit of adhesion. These

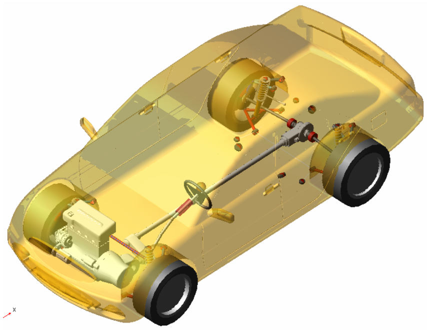

Fig. 3. Vehicle multi-body model

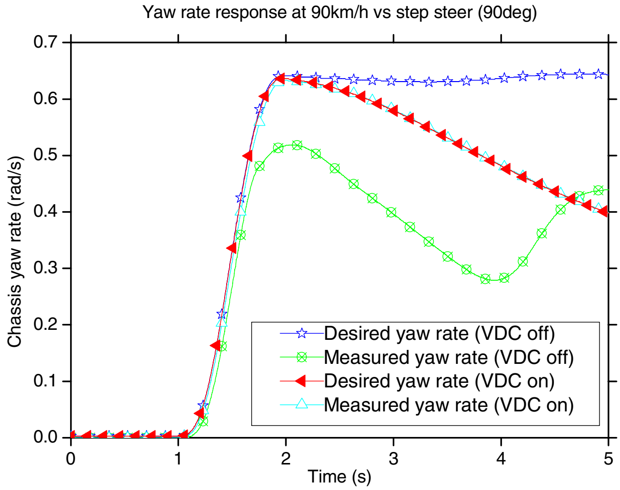

Fig. 4. Desired and measured yaw rate response

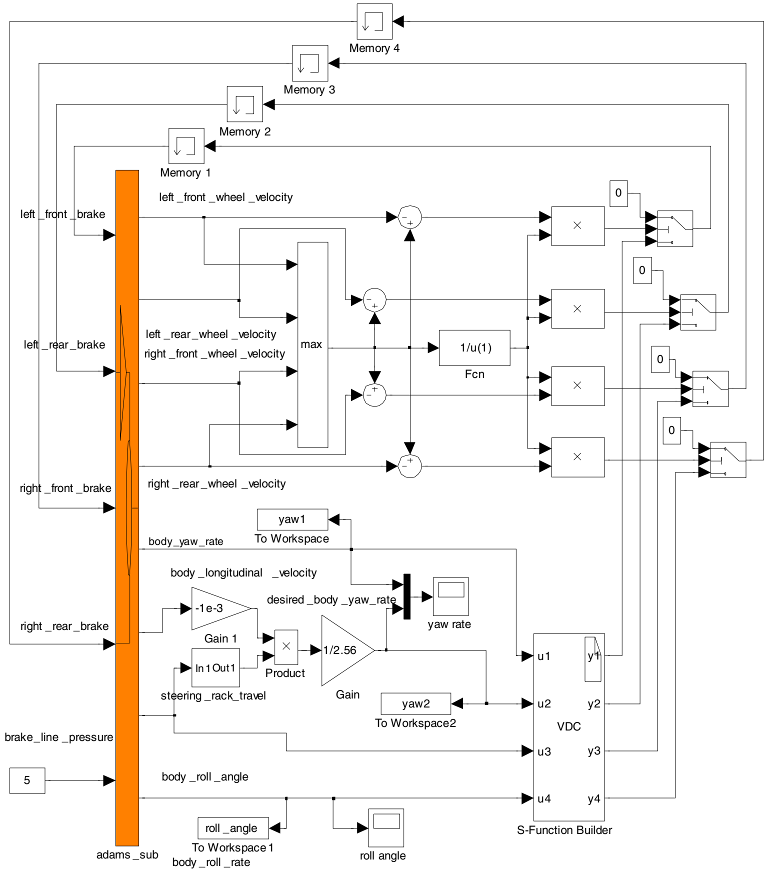

Fig. 5. Vehicle dynamics control co-simulation with ADAMS/CAR and Simulink

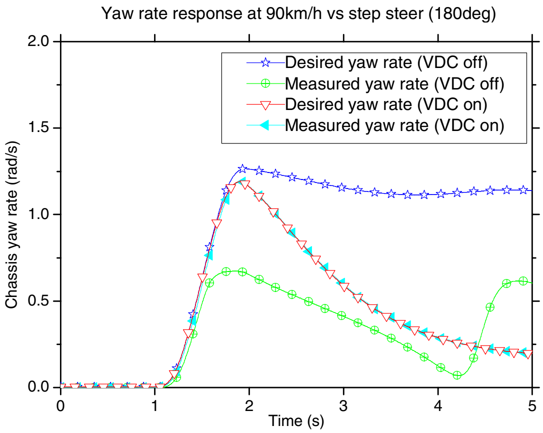

Fig. 6. Desired and measured yaw rate response

systems usually seek to bring the vehicle as closely as possible to a desired path and/or to minimize the lateral movement of the tires relative to the road surface. Fig. 4 and fig. 6 show that without VDC the vehicle tends to unstable as the steer angle increase. So under emergency, the driver is definite to lost control on the vehicle without VDC. The control system is configured to bring the vehicle yaw rate into correspondence with a desired yaw rate value.

The program codes in VDC (S-Function Builder) in fig. 5 are shown in the following:

```
if(u3[0]>=0.001) /*u3[0] is the steer rack displacement, i.e. steering angle*/
{
    if(u2[0]-u1[0]>=0.001) /*u2[0] is the desired yaw rate*/
    {                                   /*u1[0] is the measured yaw rate*/
          y1[0] = 0;           /*y1[0] is the output for left front brake*/
          y2[0] = (u2[0]-u1[0])*20;
          y3[0] = 0;      /*y3[0] is the output for right front brake*/
          y4[0] = 0;                /*y4[0] is the output for right rear
    brake*/
    }
    else if(u2[0]-u1[0]<=-0.001)
    {
          y1[0] = 0;
          y2[0] = 0;           /*y2[0] is the output for left rear brake*/
          y3[0] = -5*(u2[0]-u1[0])*20;
          y4[0] = 0;
    }
    else
    {
          y1[0] = 0;
          y2[0] = 0;
          y3[0] = 0;
          y4[0] = 0;
    }
}
else if(u3[0]<=-0.001)
{
    if(u2[0]-u1[0]<=-0.001)
    {
          y1[0] = 0;
          y2[0] = 0;
          y3[0] = -5*(u2[0]-u1[0])*20;
          y4[0] = 0;
    }
    else if(u2[0]-u1[0]>=0.001)
    {
          y1[0] = 0;
          y2[0] = (u2[0]-u1[0])*20;
          y3[0] = 0;
          y4[0] = 0;
    }
    else
    {
          y1[0] = 0;
```

```
                y2[0] = 0;
                y3[0] = 0;
                y4[0] = 0;
        }
}
```

5 Anti-rollover Control Strategy

Existing vehicle dynamics control systems may aid in preventing a vehicle from spinning out, and hence may indirectly reduce the potential for the vehicle to have a side collision with a barrier thus reducing the likelihood of a rollover. For under-steer vehicle, the vehicle dynamics control system will manage to make the vehicle neutral-steer, as shown in fig. 4 and fig. 6. However, this action will unintentionally increase vehicle lateral acceleration and roll displacement, which will definitely deteriorate roll stability.

Fig. 7 shows that the chassis roll angle response to the step steer. A big increase can be seen in chassis roll angle at 1.8 second with VDC on comparing to VDC off, which will lead to the vehicle rollover in some cases. Without VDC, there is a little unstable at 4.5 second since big sharp step steer. In contrast to VDC off, the roll angle tends to stable mostly because of the reduction in the vehicle speed.

The prerequisite to prevent rollover in this paper is that the vehicle is equipped with active suspension, and the actuator's location is shown in fig. 8. The force of the actuator is determined by the chassis roll angle, roll rate, vehicle speed and steer angle. The control system is shown in fig. 9.

The roll angle reduced dramatically with anti-rollover control, as shown in fig. 10. Comparing to the roll angle with VDC on, the roll angle with VDC on and ARC on is cut off by 50%, which will improve the vehicle stability to prevent rollover, as well as the passenger's comfortability.

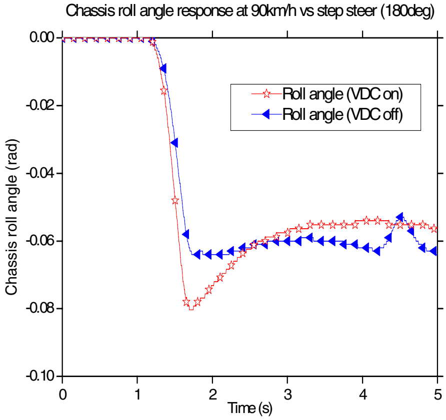

Fig. 7. Chassis roll angle response

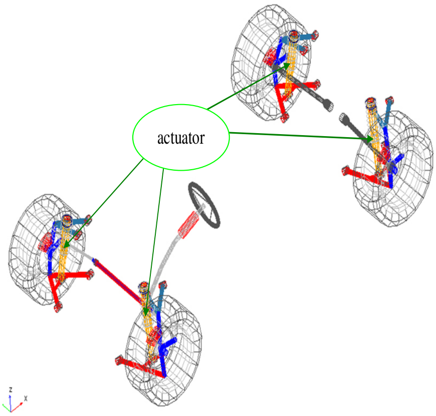

Fig. 8. Actuator's location

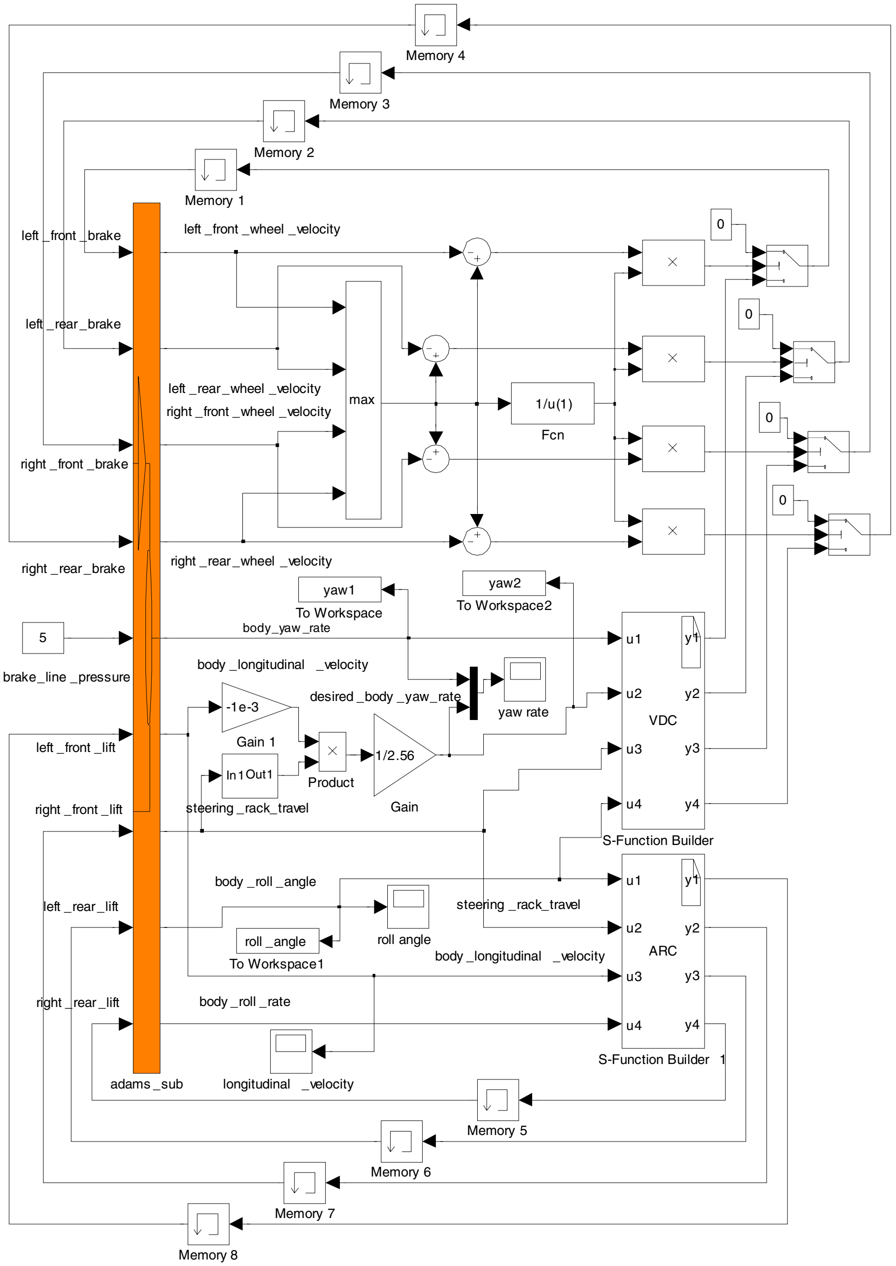

Fig. 9. Vehicle anti-rollover control co-simulation with ADAMS/CAR and Simulink

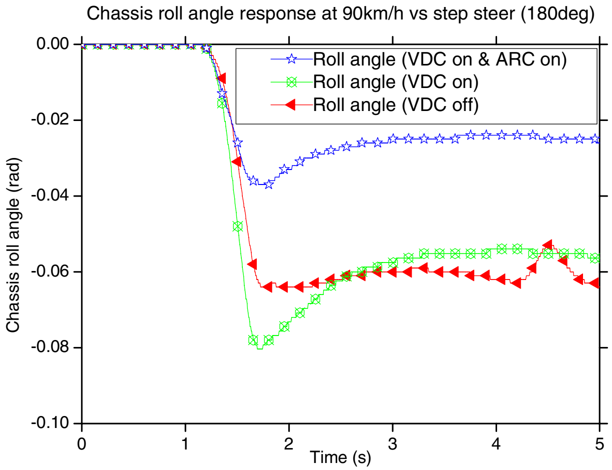

Fig. 10. Chassis roll angle response

6 Conclusions

The paper proposes a vehicle dynamics control strategy devoted to prevent vehicles from spinning and drifting out on high speed obstacle avoidance under emergency. With dynamics control system, counter braking is applied at individual wheels as needed until steering control and vehicle stability are regained. However, vehicle dynamics control system may not react properly to, or even deteriorate many on-road rollover events. An anti-rollover control system was developed to prevent rollover. With this improved control system, the vehicle can afford nice manoeuvrability and passenger comfortability.

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