Vehicle Yaw Stability Control and its Integration with Roll Stability Control

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Abstract: The paper presents a vehicle yaw stability control (YSC) strategy devoted to prevent vehicles from spinning and drifting out. With yaw stability control system, counter braking was applied at individual wheels as needed until steering control and vehicle stability were regained. However, YSC system may not react properly to, or even deteriorate many on-road rollover events. An integration control system, vehicle dynamics control system (VDC), including yaw stability control and roll stability control was presented and discussed. With this improved control system, the vehicle can afford nice manoeuvrability and stability.

Key Words: Yaw Stability Control, Roll Stability Control, Rollover, Vehicle Dynamic Control

1 INTRODUCTION

Vehicle yaw stability control system that prevent vehicles from spinning, drifting out and rolling over have been developed and recently commercialized by several automotive manufacturers [1]-[2].

When ABS was first introduced back in the mid-1980s, it was strictly a braking system for preventing wheel lockup and skidding. Then traction control was added as the technology evolved to prevent wheel spin during acceleration. Then came an advancement that would take ABS to an entirely new level. Vehicle yaw stability control allows ABS systems to automatically brake individual wheels as needed to improve handling and steering control under all driving conditions.

Vehicle yaw stability 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 a problem starts to develop, it springs into action and takes whatever measures are necessary to get things back under control. This includes reducing engine power by backing off the throttle and/or retarding spark timing, and simultaneously applying one or more brakes to counter the forces that are causing the vehicle to lose control and/or traction. The neat thing is that all this happens automatically without any driver input [3]-[5].

YSC systems use automatic computer-controlled braking of individual wheels to help the driver maintain control in situations where a vehicle without YSC would skid out of control and likely leave the road. Figure 1 shows two traffic scenarios.

In Figure 1(A) the vehicle is understeering. In effect it is trying to continue straight ahead and the driver needs to apply more steering effect in order to get round the bend. Stability control can assist here by applying some braking at the rear of the vehicle, to the wheel on the inside of the bend. This produces a correcting action that assists in 'swinging' the vehicle, in a smooth action, back to the intended direction of travel.

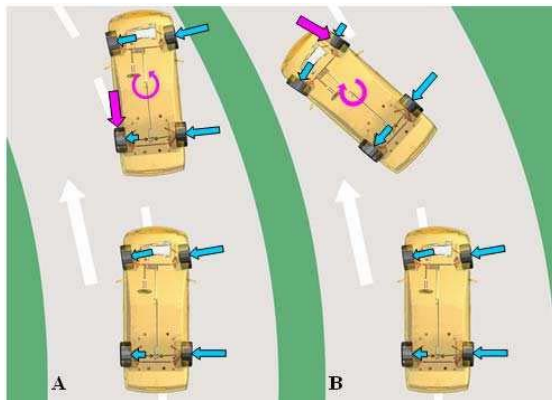

Fig 1. YSC works situation

In Figure 1(B) 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. In order to counter oversteer, the wheel brakes on the outside of the turn can be applied and/or the engine power reduced, via the secondary throttle, by the computer.

The proposed National Highway Traffic Safety Administration (NHTSA) rule would require all manufacturers to begin equipping passenger vehicles under 10,000 pounds with VDC starting with the 2009 model year and to have the system available as standard equipment on all vehicles by the 2012 model year or September 2011 when the model year begins. Therefore, vehicle dynamics control system will definitely receive more attention.

2 HOW YSC SYSTEM WORKS

To better control vehicle dynamics under all driving conditions, the YSC 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

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changes in vehicle momentum that might cause the vehicle to spin out, oversteer or understeer, and a lateral acceleration (g-force) sensor to monitor changes in deceleration [6]-[7].

When the driver steers the vehicle, the steering angle sensor keeps the YSC 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 YSC control module looks at the inputs from its wheel speed sensors to 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.

If a vehicle begins to oversteer in a turn and the rear end starts to come around (which would cause the car to spin out), the speed difference between the left and right front wheels increases. If the vehicle understeers (loses front traction and goes wider in a turn), the speed difference between the left and right front wheels decreases.

If the stability control software in the YSC control module detects a difference in the normal rotational speeds between the left and right wheels when turning, it immediately reduces engine power and applies counter braking at individual wheels as needed until steering control and vehicle stability are regained.

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 velocity, lateral acceleration, and curvature, may be regarded as outputs.

Yaw velocity 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 velocity to the steer angle. Yaw velocity ω_r of the vehicle under steady-state conditions is the ratio of the forward speed u to the turning radius R. The yaw velocity 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. Equation 1 gives the yaw velocity gain with respect to the steer angle of the front wheel. If the yaw velocity gain with respect to the steering wheel angle is desired, the value obtained from formula (1) should be divided by the steering gear ratio [8].

For a neutral steer vehicle, the understeer coefficient K is zero; the yaw velocity gain increases linearly with an increase of forward speed. For an understeer vehicle, the understeer coefficient K is positive. The yaw velocity 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 velocity gain increases with the forward speed at an increasing rate. Since K is negative, at a particular speed, the denominator of formula (1) is zero, and the yaw velocity 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 velocity of neutral steer vehicle ω_0 can be obtained from formula (1):

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

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

4 YSC CONTROL STRATEGY

The yaw velocity of steady-state is determined by the steering input and vehicle forward speed in a large extent. The yaw velocity increases with the vehicle speed in the same steering angle, as shown in Figure 2. Figure 2 shows that the yaw velocity tends to be unstable if the speed is excessive. So we need to control the yaw velocity and the speed if necessary.

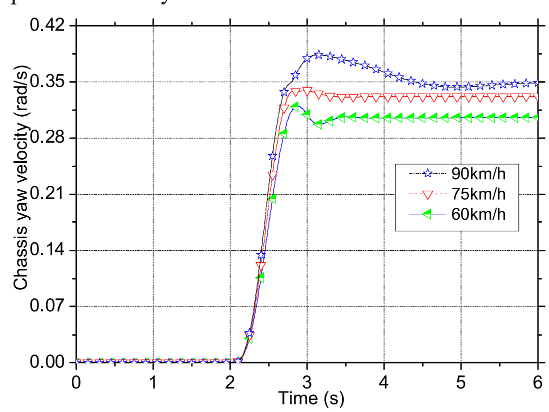

Fig 2. Yaw velocity determined by the vehicle speed

Figure 3 is the desired yaw velocity (neutral steer) and the measured yaw velocity without vehicle dynamics control system. The desired yaw velocity was obtained from formula (2). Formula (2) shows that the desired yaw velocity is only determined by the forward speed and the front wheel steering angle. Therefore, if the forward speed and the front wheel steering angle are measured, the desired yaw velocity is obtained. Figure 3 reveals that the difference between the desired yaw velocity and the measured yaw velocity increases with the vehicle speed. The target of vehicle yaw stability control system is to eliminate or reduce the difference.

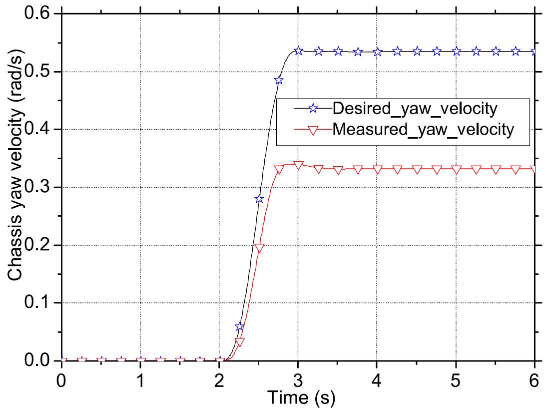

Fig 3. Desired yaw velocity and measured yaw velocity without YSC

Vehicle yaw stability control system can actively brake individual wheels in an effort to improve vehicle stability or handling near and at the limit of adhesion. These 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. Typically, the control is configured to bring the vehicle yaw rate into correspondence with a desired yaw rate value.

YSC main principle is as follows: when regulation at wheel is needed, it injects a certain volume of fluid in the brake and expects a certain braking pressure and torque. If the torque is too high, it removes a given volume of fluid and waits for a predictable reduction of pressure and torque. The regulation system is an open loop as no pressure sensor indicates the real wheel brake pressure.

We employ the linear bicycle model to generate the reference vehicle behavior, such as yaw velocity of neutral steer. The difference of yaw velocity between the reference model and the multi-body model is considered as control signal to the vehicle multi-body model. The vehicle dynamics control principle is shown in Figure 4, and the vehicle multi-body model is shown in Figure 5.

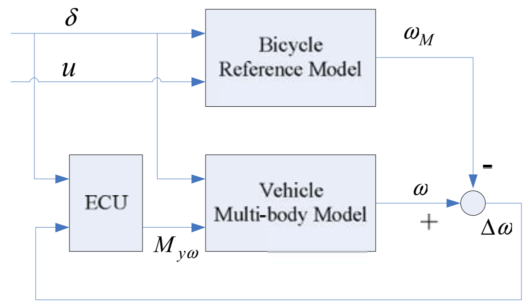

Fig 4. Vehicle yaw stability control principle

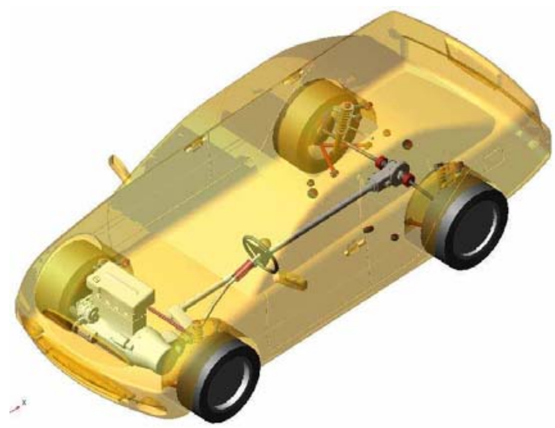
Fig 5. Vehicle multi-body model

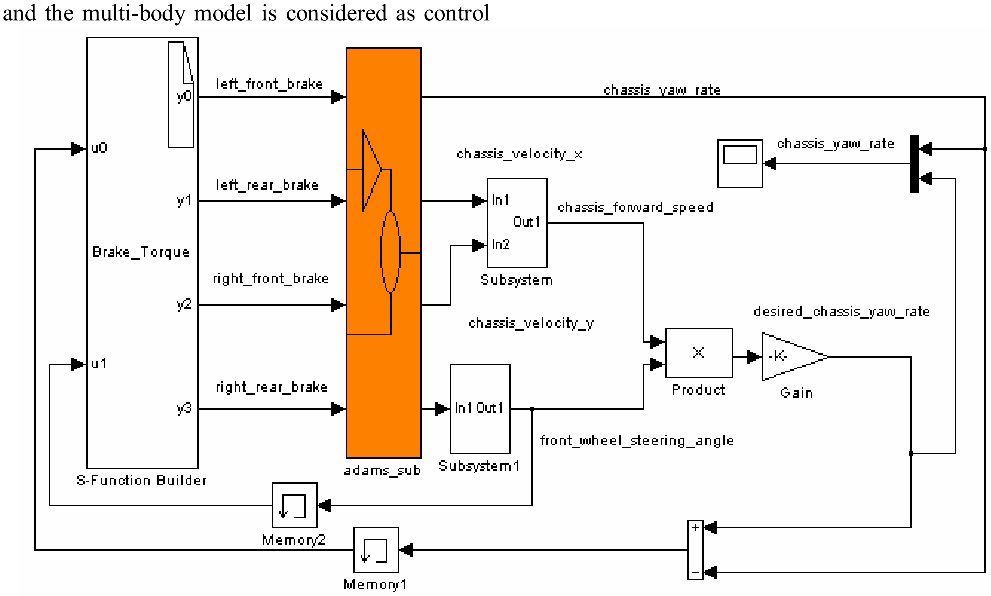

Fig 6. Co-simulation of yaw stability control using ADAMS and Simulink

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 Figure 5, and the control system is shown in Figure 6.

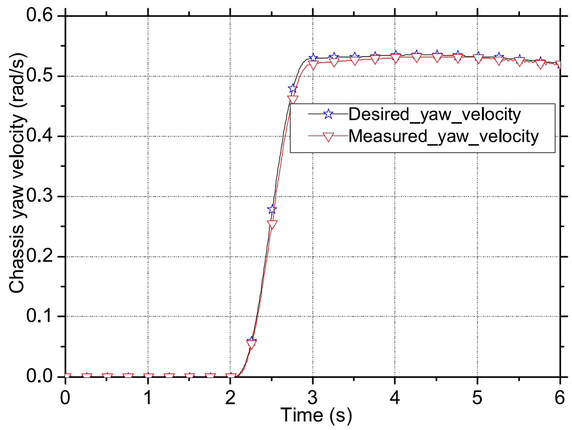

Fig 7. Desired yaw velocity and measured yaw velocity with YSC

Figure 7 is the chassis yaw velocity with vehicle yaw stability control system. From Figure 3 and Figure 7, we can see that the vehicle without YSC has an understeer characteristic. The yaw velocity under vehicle dynamics control is very close to the desired yaw velocity (neutral steer). In addition, as shown in Figure 7, the desired yaw velocity is not steady after step steer and decreases after 3 second. The reason is that the vehicle speed reduces due to the brake.

5 Vehicle Dynamics Control

Existing yaw stability 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 yaw stability control system will manage to make the vehicle neutral-steer, as shown in Figure 7. However, this action will unintentionally increase vehicle lateral acceleration and roll displacement, as shown in Figure 8 and Figure 9, which will definitely deteriorate roll stability.

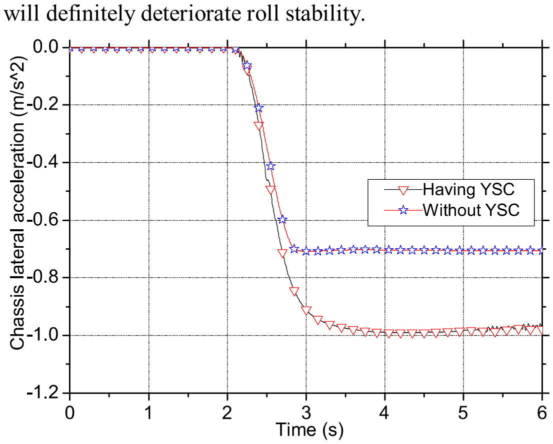

Fig 8. Vehicle lateral acceleration

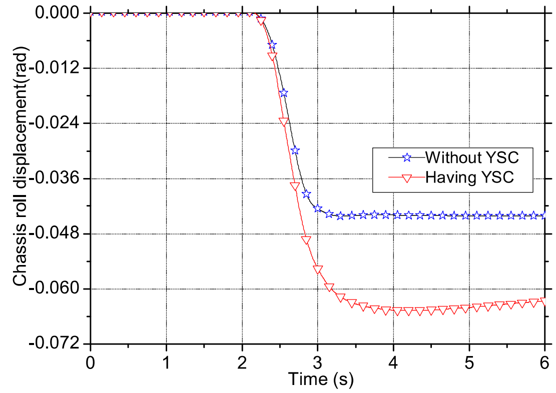

Fig 9. Vehicle roll displacement

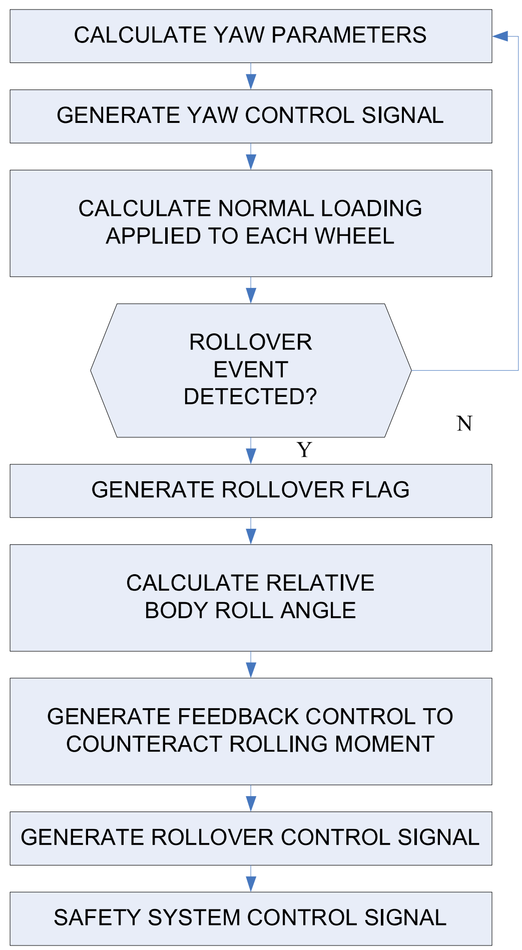

Fig 10. Vehicle dynamics control principle

The roll stability control system, however, needs to make the vehicle under-steer more during the detected aggressive driving conditions that may contribute to vehicle roll instability. Intentionally making the vehicle under-steer (as required for roll stability control) and intentionally making the vehicle neutral-steer (as required for yaw stability control) are two different objectives.

Notice, however, that if a near-rollover event is caused by an aggressive over-steer, the yaw stability control system might help improve roll stability due to the fact that it brings the vehicle to neutral-steer so as to reduce the amount of vehicle over-steer. It is therefore desirable to provide an enhanced yaw stability control system, vehicle dynamics control (VDC), such that the traditional yaw stability function is preserved and at the same time the system will directly and properly react to potential vehicular rollover events.

Vehicle dynamics control system utilizes sensors on the vehicle to detect if a rollover is imminent and a corrective action is required. If corrective action is required, differential braking is used both to slow the vehicle down and to induce an understeer that contributes to reduction in the roll angle rate of the vehicle. The principle of vehicle dynamics control is shown in Figure 10.

Vehicle dynamics control system, including yaw stability control and roll stability control, is shown in Figure 11. This system includes a steering angle sensor to monitor the driver's steering inputs, a yaw sensor to detect changes in vehicle momentum, a roll sensor to monitor chassis roll displacement, and a lateral acceleration (g-force) sensor to monitor changes in deceleration.

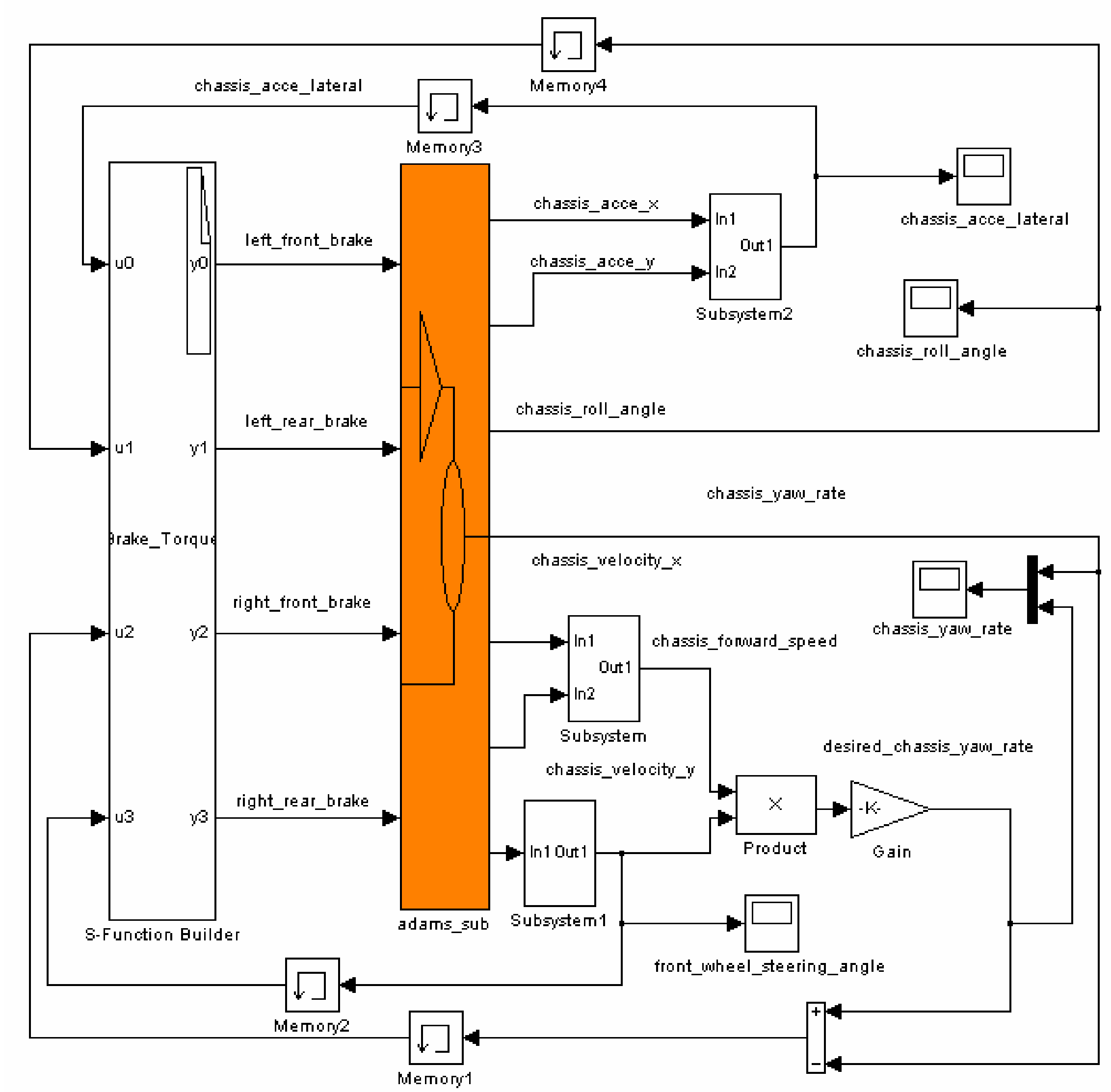

Fig 11. Co-simulation of vehicle dynamics control using ADAMS and Simulink

Figure 12 is the vehicle roll displacement. Comparing to vehicle yaw stability control system, the roll displacement with vehicle dynamics control system reduces obviously. With VDC, the actual yaw velocity can still follow the desired yaw velocity, but the difference between desired yaw velocity and actual yaw velocity increases comparing to Figure 7. The desired yaw velocity in Figure 13 decreases further because of much brake on the wheel.

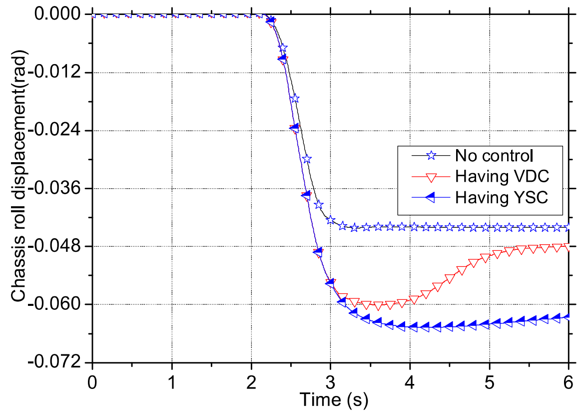

Fig 12. Vehicle roll displacement

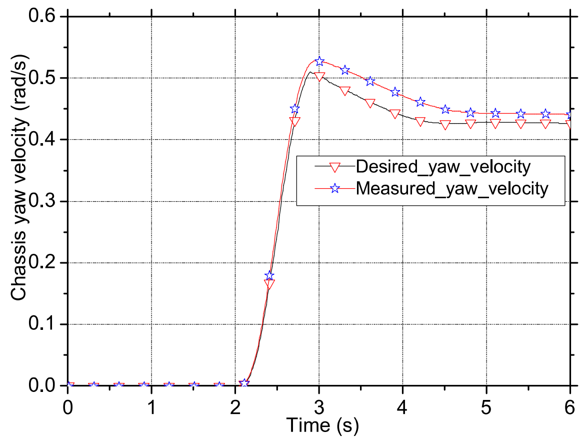

Fig 13. Desired yaw velocity and measured yaw velocity with VDC

6 CONCLUSIONS

The paper proposes a vehicle yaw stability control (YSC) strategy devoted to prevent vehicles from spinning and drifting out. With yaw stability control system, counter braking is applied at individual wheels as needed until steering control and vehicle stability are regained. However, YSC system may not react properly to, or even deteriorate many on-road rollover events. An integration control system, vehicle dynamics control system (VDC), including yaw stability control and roll stability control was presented and discussed. With this improved control system, the vehicle can afford nice manoeuvrability and stability.

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