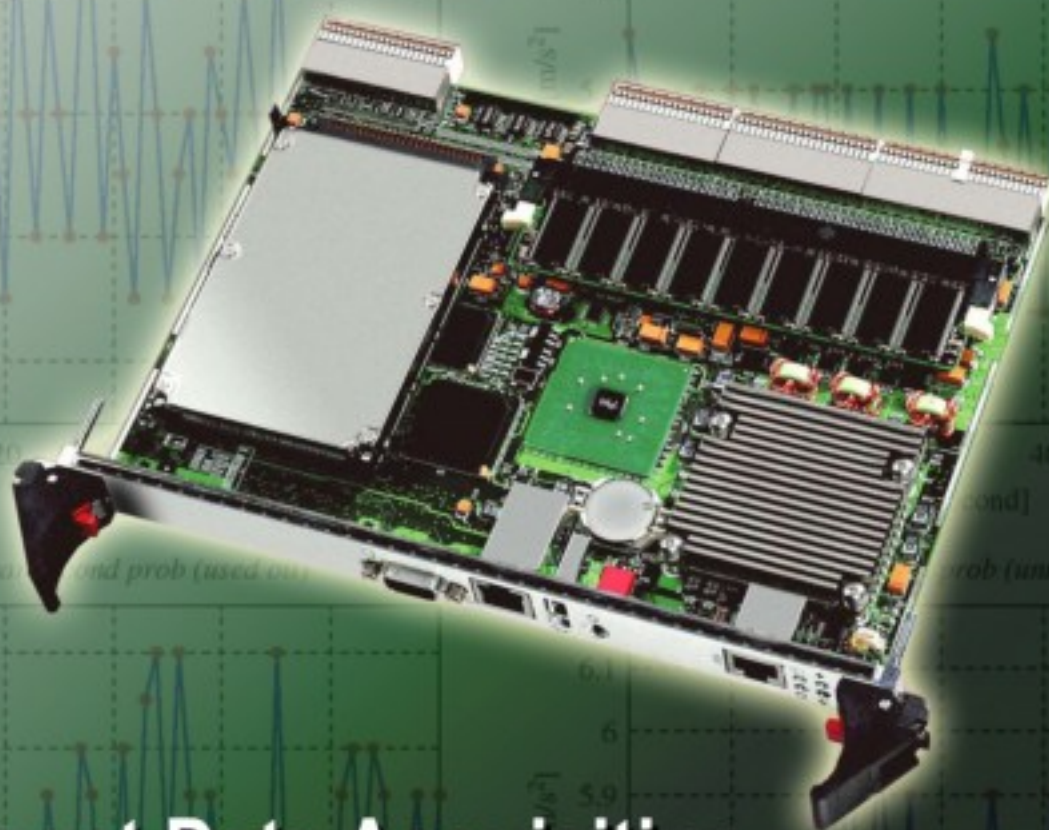


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International Frequency Sensor Association Publishing



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Jackknife Control on Tractor Semi-trailer during High Speed Curve Driving

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Abstract: In this paper, the tractor semi-trailer kinematics was analyzed and a 3-dof model was used to design a full-order observer to estimate the articulation angle. The anti-jackknife control proposed in this paper will try to minimize tracking error between the desired tractor semi-trailer yaw rates and the actual yaw rates by selectively actuating braking system associated with the wheels of the tractor semi-trailer as soon as the articulation exceeds a preset threshold. The dynamics simulation results show that the anti-jackknife control system can improve the tractor semi-trailer lateral stability during high speed curve driving. *Copyright © 2012 IFSA.*

Keywords: Tractor semi-trailer, Anti-jackknife, Lateral stability, Curve driving.

1. Introduction

A tractor semi-trailer, also known as articulated vehicle is an articulated truck consisting of a tractor and a semi-trailer that carries the freight. Handling behaviour of articulated vehicles is more complex and less predictable than that of non-articulated vehicles. In addition, the response of the semi-trailer to inputs from the tractor, such as steering manoeuvres, is typically amplified and lags behind the response of the tractor making it difficult to control. This often causes stability problems and a semi-trailer may start to jackknife or roll excessively before the driver is aware of the problem and, therefore, may not have time to take corrective action [1].

Two phenomena, rollover and jackknife usually emerge in the tractor semi-trailer during high speed curve driving. A rollover can result when a tractor semi-trailer with a high center of gravity negotiates a

turning maneuver on high friction road surface [2, 3]. Jackknife is another somewhat common condition that is caused when the driving speed exceeds a threshold, causing lateral thrust and resulting in vehicle slide on a road surface with a lower coefficient of friction, usually a wet surface [4, 5]. Fig. 1 shows the jackknife during high speed curve driving.

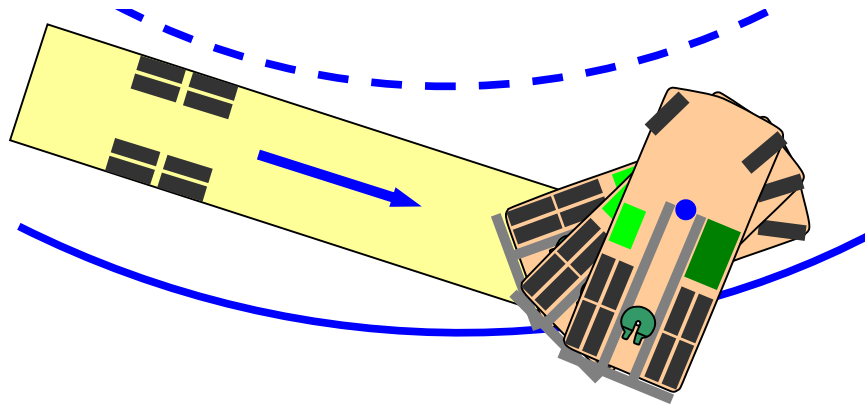


Fig. 1. Jackknife during high speed curve driving.

Undoubtedly, these jackknife accidents can be fatal during high speed curve driving. In this paper, an electronic stability control system (ESC) using a sliding mode control technique is proposed to prevent the jackknife during high speed curve driving, which will help the driver maintain yaw stability of the tractor semi-trailer on a low friction surface.

A three degree of freedom (3-DOF) tractor semi-trailer lateral dynamic model was derived. Based on the 3-DOF model, several desired state variables can be obtained. The electronic stability control system proposed in this paper will try to minimize tracking error between the desired tractor semi-trailer yaw rates and the actual yaw rates by selectively actuating braking system associated with the wheels of the tractor semi-trailer as soon as the articulation exceeds a preset threshold.

2. Desired State Variables

The desired state variables can be solved through the simplified dynamics equations of three degrees of freedom tractor semi-trailer model, as shown in Fig. 2 [6-8].

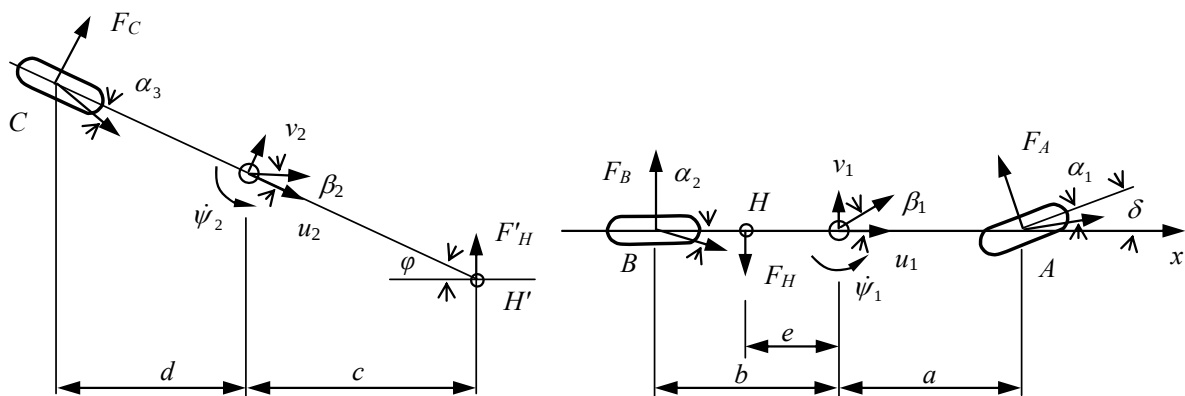


Fig. 2. Three degrees of freedom tractor semi-trailer model.

In developing the equations of motion for the yaw plane model, the roll dynamics of the tractor semi-trailer are neglected. Also, the tractor semi-trailer is assumed to travel at a constant forward velocity. The degrees of freedom permitted in the model are therefore limited to lateral and yawing motion of the tractor and the semi-trailer units [8-10]. The articulation angle is related through the yaw angles of the two units. The effect of the centrifugal force is therefore neglected so that the model is kinematic. The vehicle is also assumed to be moving on a hard, flat surface.

$$m_1 u (\dot{\beta}_1 + \dot{\psi}_1) = C_{\alpha 1} \alpha_1 + C_{\alpha 2} \alpha_2 - F_H \quad (1)$$

$$m_2 u (\dot{\beta}_2 + \dot{\psi}_2) = C_{\alpha 3} \alpha_3 + F'_H \quad (2)$$

$$I_{z1} \ddot{\psi}_1 = a C_{\alpha 1} \alpha_1 - b C_{\alpha 2} \alpha_2 + e F_H \quad (3)$$

$$I_{z2} \ddot{\psi}_2 = c F'_H - d C_{\alpha 3} \alpha_3, \quad (4)$$

where

$$\begin{aligned} \alpha_1 &= -\delta + \beta_1 + \frac{a \dot{\psi}_1}{u}, \quad \alpha_2 = \beta_1 - \frac{b \dot{\psi}_1}{u}, \\ \alpha_3 &= \beta_1 - \frac{(e+c+d) \dot{\psi}_1}{u} - \frac{(c+d) \dot{\phi}}{u} - \varphi, \\ \beta_2 &= \beta_1 - \frac{(e+c) \dot{\psi}_1}{u} - \frac{c \dot{\phi}}{u} - \varphi, \quad \dot{\psi}_2 = \dot{\psi}_1 + \dot{\phi}. \end{aligned}$$

Introducing $\mathbf{x} = [\dot{\psi}_1 \quad \beta_1 \quad \dot{\phi} \quad \varphi]^T$ as a new state vector variable, we form the vector the tractor semi-trailer model can be rewritten in state-space representation:

$$\dot{\mathbf{x}} = \mathbf{A}\mathbf{x} + \mathbf{B}\delta \quad (5)$$

The desired state variables, such as tractor's yaw rate, semi-trailer's yaw rate and articulation angle can be obtained by solving the equation (5).

3. Articulation Angle Estimation

The intervention condition of anti-jackknife control depends on the articulation angle of the tractor semi-trailer. However, the value of articulation angle must be estimated as described below since it cannot be or is difficult to be measured directly.

The tractor semi-trailer sensor values are used in the estimation of articulation angle and lateral velocity. These sensors include a steering angle sensor to monitor the driver's steering inputs, two yaw sensors to detect changes in tractor and semi-trailer momentum, two lateral acceleration sensors and a vehicle speed sensor etc.

The state parameters of tractor semi-trailer can be estimated with full-order observer, as shown in Fig. 3.

Fig. 4. is the control block diagram of state parameters of tractor semi-trailer estimated with full-order observer in Simulink. The gain matrix can be determined using the pole placement method.

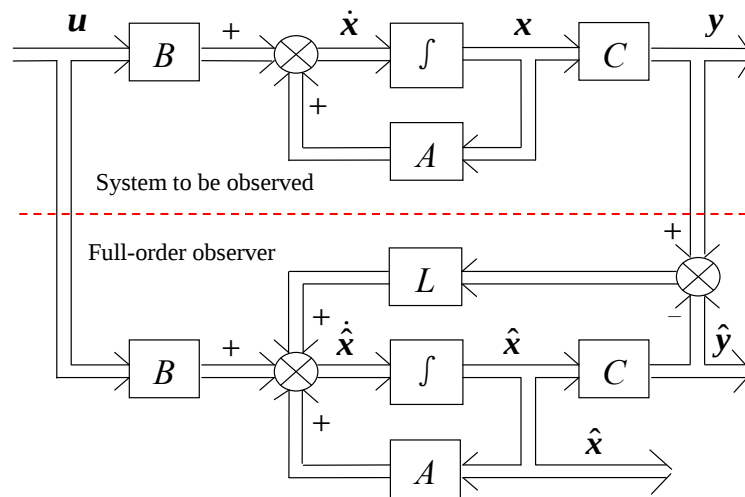


Fig. 3. Full-order observer.

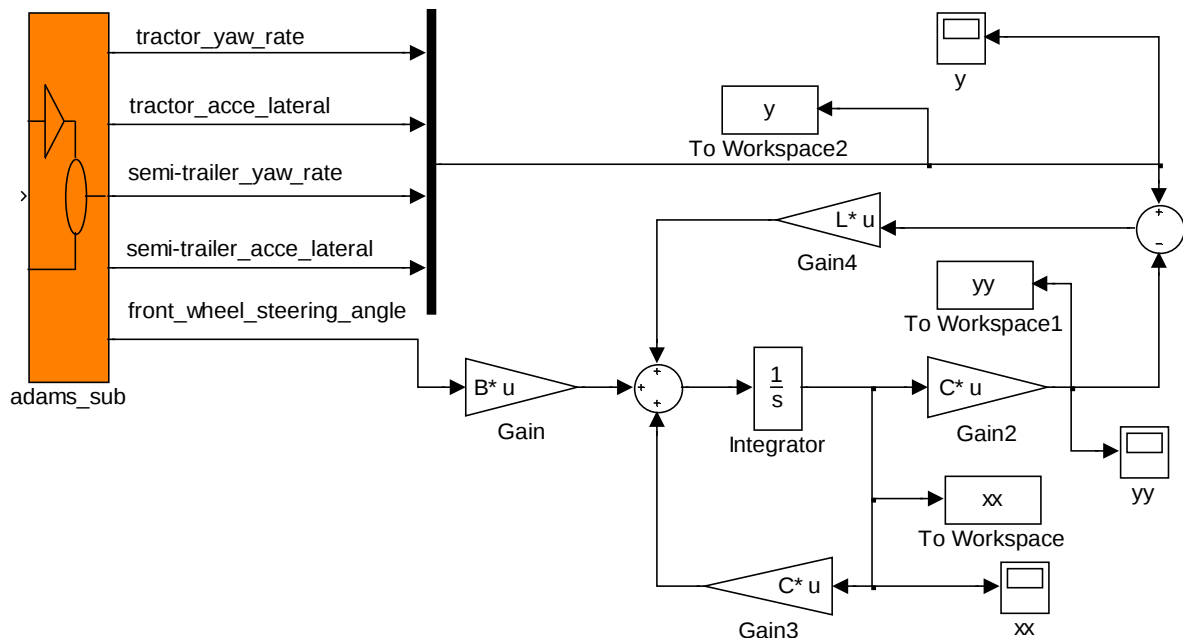


Fig. 4. State parameters of tractor semi-trailer estimated with full-order observer in Simulink.

4. Anti-jackknife Control

Once the jackknife is detected, the traditional anti-folding control is to apply brake on the front outer wheel of the tractor and all the wheels of the semi-trailer, as shown in Fig. 5.

The biggest advantage of traditional anti-jackknife control is that the speed of tractor semi-trailer can be reduced as quickly as possible. So the jackknife can be prevented to a large extent. But one of the biggest shortcomings is the impact of load transfer that can produce an additional torque deteriorating the lateral stability of tractor semi-trailer, accelerating the jackknife.

Therefore, the new anti-jackknife control proposed in this paper will apply brake on the front outer wheel of the tractor and inner wheels of the semi-trailer, as shown in Fig. 6.

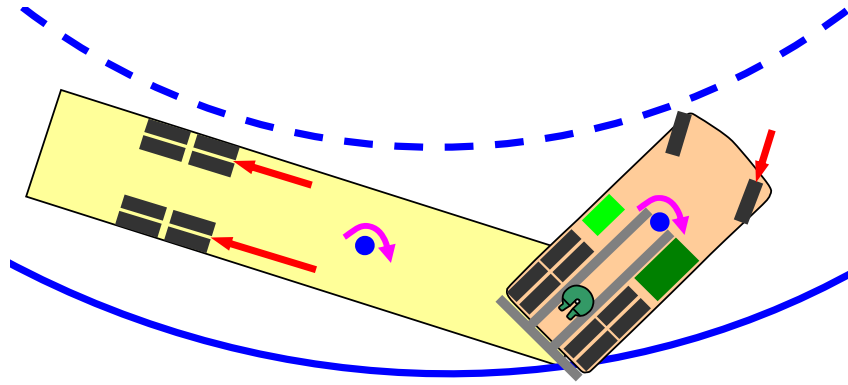


Fig. 5. Traditional anti-jackknife control.

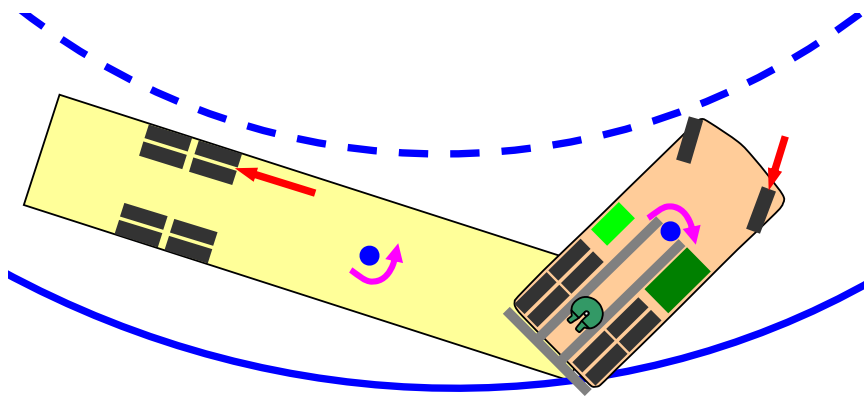


Fig. 6. New anti-jackknife control.

5. Dynamics Simulation

In order to verify the anti-jackknife control strategy, we performed a dynamic simulation using ADAMS/CAR and Simulink. The control system was designed in Simulink, as shown in Fig. 7 and the full tractor semi-trailer was assembled in ADAMS/CAR, as shown in Fig. 8.

The initial speed of the tractor semi-trailer was set to 70 km/h, and the steering wheel was step input (see Fig. 9), which simulate high speed through the corner.

The full-order observer continuously calculates the articulation angle using the steering angle of the front wheel, yaw rates of tractor and semi-trailer, and vehicle speed. If the articulation angle estimated exceeds the pre-set threshold, the anti-jackknife control will be activated.

Fig. 10 shows the articulation angle of tractor semi-trailer without control. As we can see from the figure, without anti-jackknife control, the jackknife will arise under this condition.

As it shown in Fig. 11 and Fig. 12, with anti-jackknife control, the tractor semi-trailer can pass through the corner with jackknife.

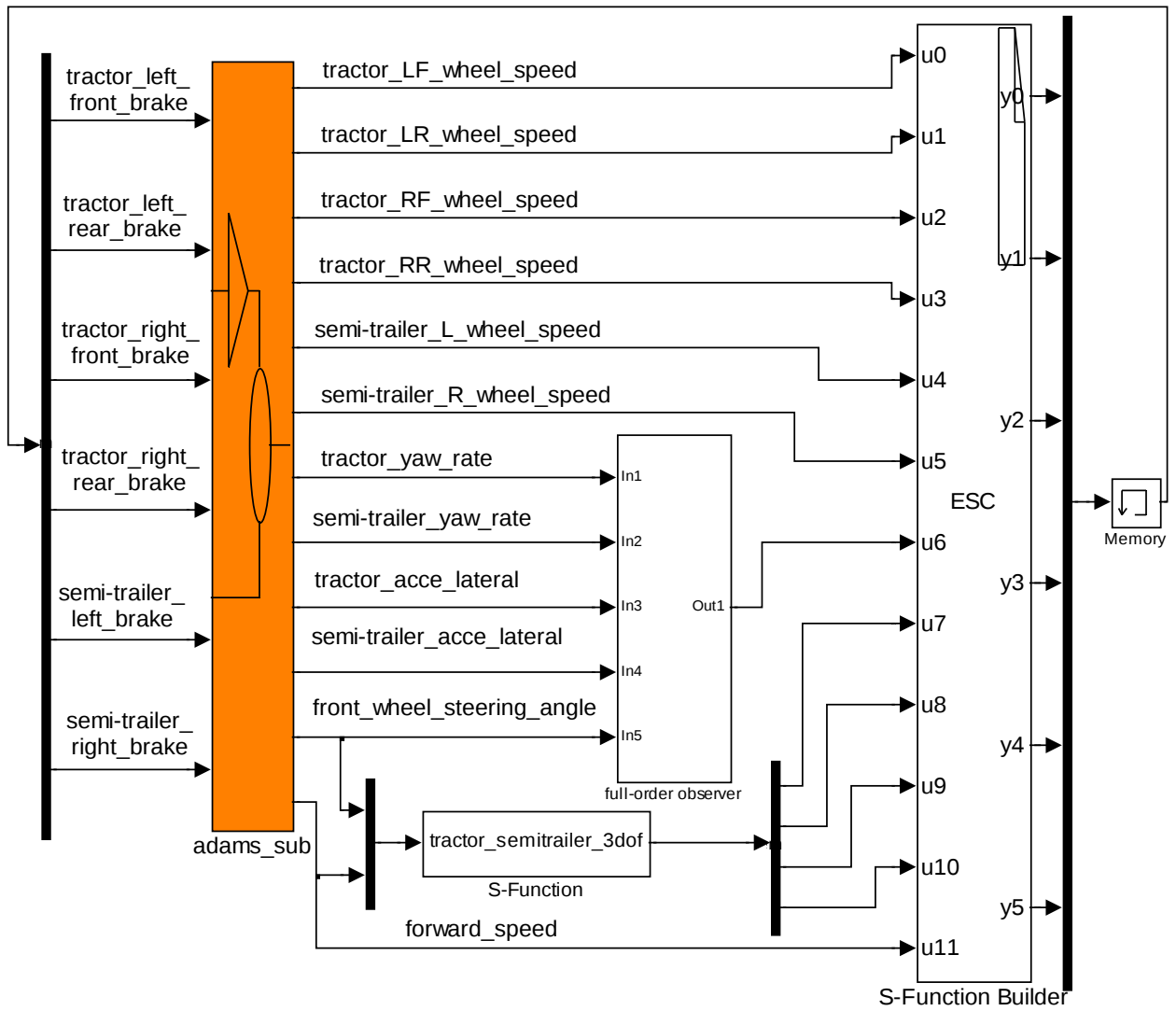


Fig. 7. Anti-jackknife control in Simulink.

_tractor_semitrailer

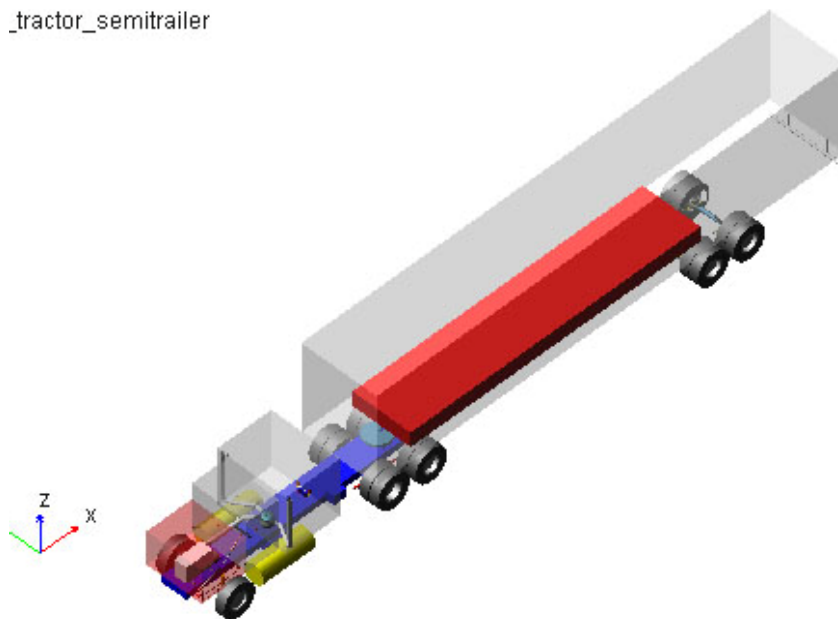


Fig. 8. Tractor semi-trailer multi-body model.

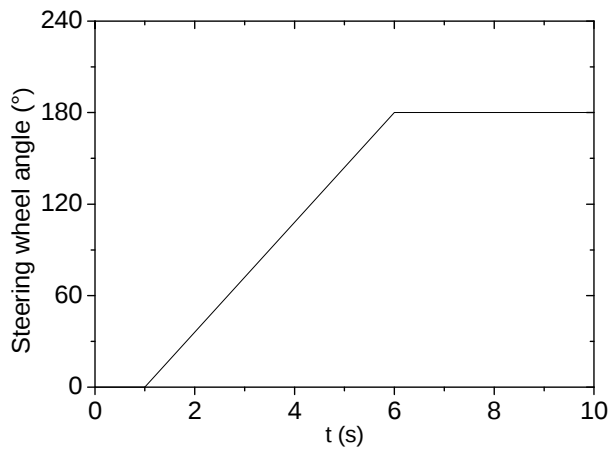


Fig. 9. Steering wheel angle.

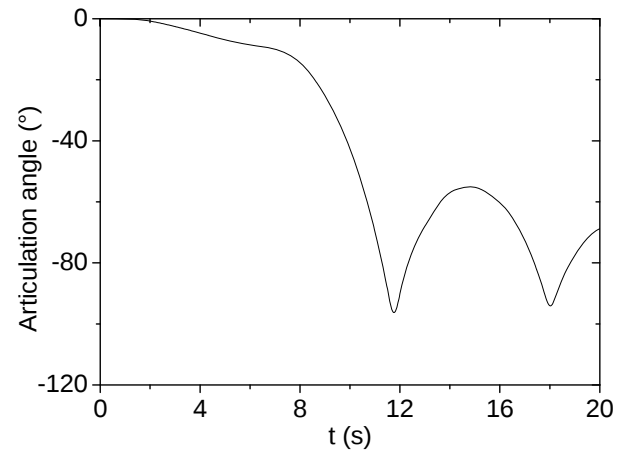


Fig. 10. Articulation angle without control.

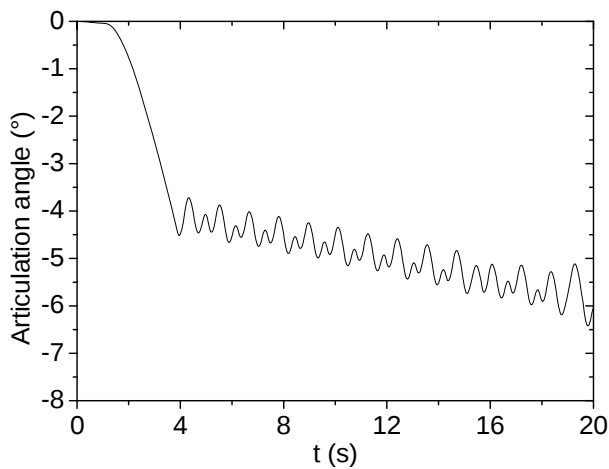


Fig. 11. Articulation angle with control.

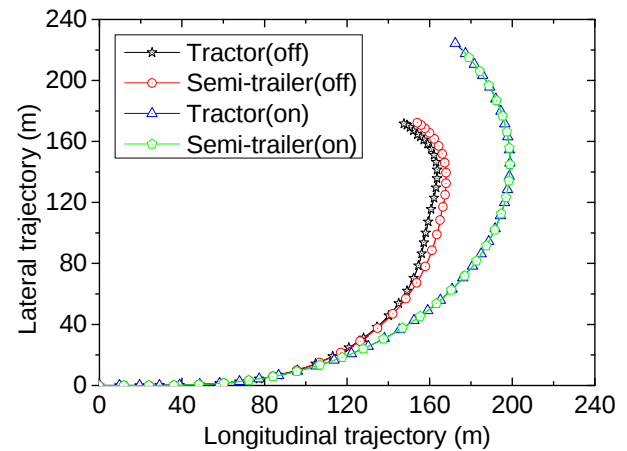


Fig. 12. Trajectories comparison.

6. Conclusions

This paper presents an anti-jackknife control for tractor semi-trailer during high speed curve driving. In this paper, a full-order observer was designed to estimate the articulation angle. The jackknife was prevented by selectively actuating braking system associated with the wheels of the tractor semi-trailer as soon as the articulation exceeds a preset threshold.

Acknowledgements

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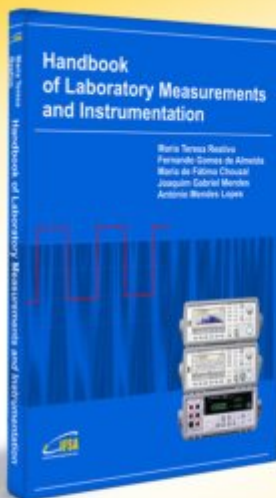
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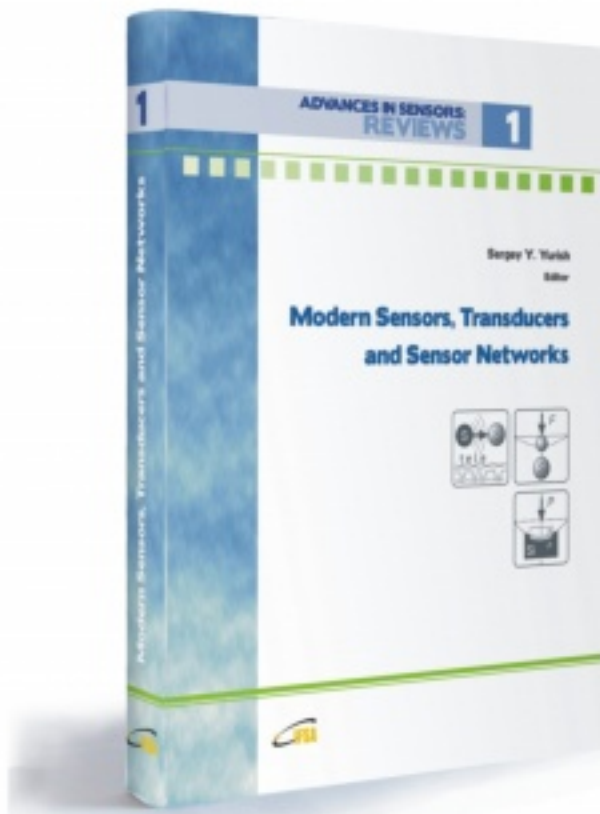
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