5
Integrated control system

The integrated control structure was designed in order to coordinate the actions of the safety system models presented in the previous sections. In this section the description, control design as well as the performance test of the integrated control structure, named here as IC, are presented.

5.1
Control design

In order to coordinate the ESP and the 4WS, a simple rule to define the action of each of these system is defined as follows:

$$IC = \begin{cases} \textbf{4WS: on \& ESP: off}, & \text{if } |\beta| \leq \beta_U \\ \textbf{4WS: off \& ESP: on}, & \text{otherwise} \end{cases} \tag{5-1}$$

where β is the sideslip angle of the vehicle. To estimate this vehicle state, the simple handling model presented in Equation (2-19) is extended for four-wheel steering vehicles and it is defined via

$$\underbrace{\begin{bmatrix} \dot{\beta} \\ \ddot{\psi} \end{bmatrix}}_{\dot{x}} = \underbrace{\begin{bmatrix} -\frac{K_f + K_r}{m|v|} & \frac{l_r K_r - l_f K_f}{m|v||v|} - \frac{v}{|v|} \\ \frac{l_r K_r - l_f K_f}{\Theta} & -\frac{l_f^2 K_f + l_r^2 K_r}{\Theta |v|} \end{bmatrix}}_{A} \underbrace{\begin{bmatrix} \beta \\ \dot{\psi} \end{bmatrix}}_{x} + \underbrace{\begin{bmatrix} \frac{K_f}{mv} & \frac{K_r}{mv} \\ \frac{v}{|v|}\frac{l_f K_f}{\Theta} & -\frac{v}{|v|}\frac{l_r K_r}{\Theta} \end{bmatrix}}_{B} \underbrace{\begin{bmatrix} \delta_f \\ \delta_r \end{bmatrix}}_{u} \tag{5-2}$$

By defining a rule that controls the use of an appropriate active safety system, e.g. ESP or 4WS, based on the sideslip angle β, it is possible to maintain the vehicle's stability in critical driving scenarios. A physical explanation of this rule Equation (5-1) is that, the average driver can recognize the vehicle behavior for small sideslip angles, i.e. far away from the tire saturation. On the other hand, skilled drivers can control the vehicle even when the tire reached the saturation, i.e. for large sideslip angles. Therefore, in this thesis, $\beta_U = 3^0$ is employed to define the actuation of the active safety system, i.e. ESP or 4WS. For sideslip value below β_U, the 4WS is used to stabilize smoothly the vehicle because the car is in a linear regime. However,

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if the sideslip becomes larger enough, a braking intervention is required in order to stabilize the vehicle, i.e. the use of the ESP. In addition, within the framework of the IC, the ABS system is always controlled by the ESP, e.g. during a selective brake intervention.

5.2 Performance test

In order to prove the benefits of the integrated vehicle control, two simulation with the same avoidance maneuver presented in Section 4 were performed. In the first one, a vehicle equipped with the ESP and 4WS without any integration between them is employed, this system will be refereed as ESP+4WS. For the second simulation, the rule to avoid the conflict between ESP and 4WS, defined before, was used.

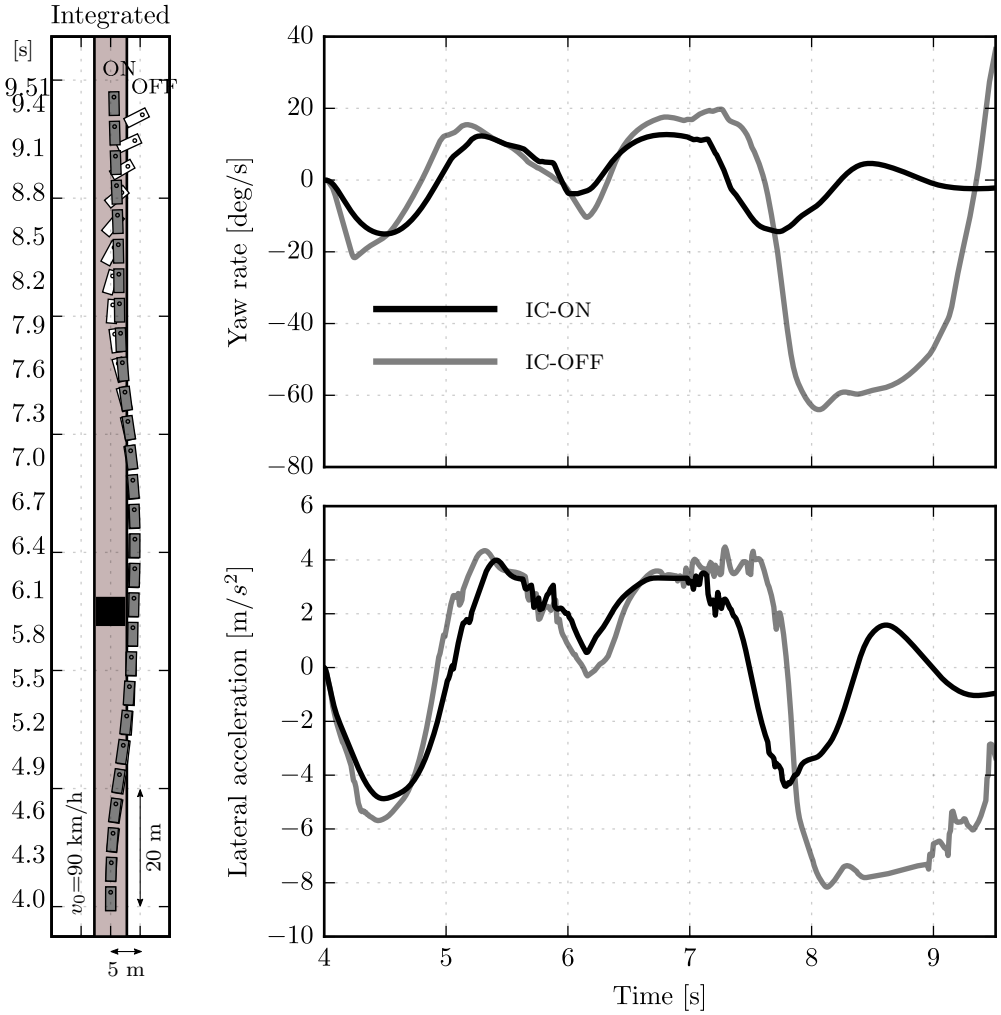

Figure 44: Trajectory and main states of a full-size vehicle during an avoiding maneuver. **Top:** yaw rate. **Bottom**: lateral acceleration. IC-ON (black line), IC-OFF (gray line).

On the multi-frame shots of Figure 44, we can notice that the vehicle

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equipped with the ESP and the 4WS without any integration, i.e. IC-OFF, becomes unstable. This is because the conflicts between the ESP and the 4WS. In addition, the lateral acceleration and the yaw rate are maintained in a safe range by the IC system as can be seen on the plots of the same figure.

Figure 45 shows the 4WS actions during the avoidance maneuver. As can be noticed on the bottom plots, the IC-OFF system saturates the rear steering wheels as can be seen on the gray region between $t \approx 7.5$ and $t \approx 8.0\,s$ approximately.

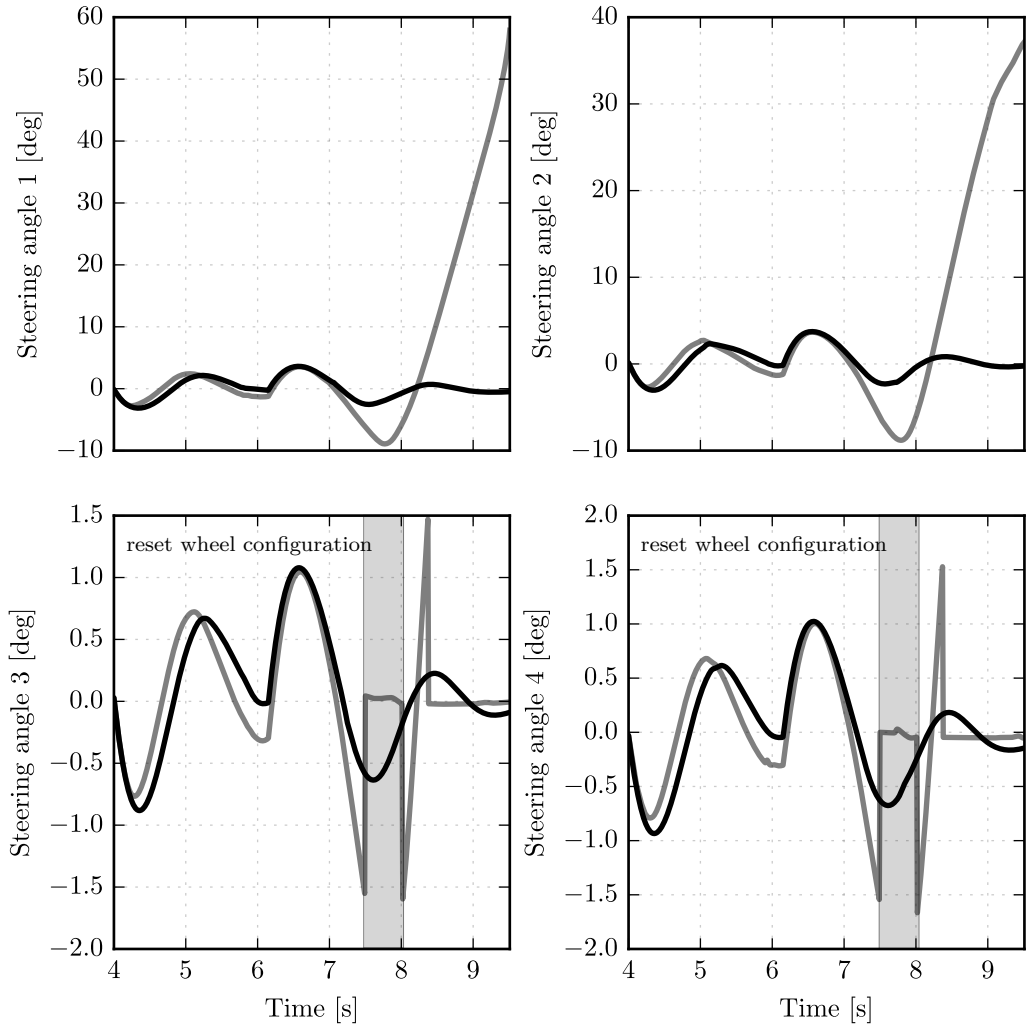

Figure 45: 4WS rear steering activations during the avoiding maneuver. **1:** front left. **2:** front right. **3:** rear left. **4:** rear right. IC-ON (black line), IC-OFF (gray line).

Furthermore in Figure 46, the ESP braking activations is displayed. As can be noticed, the IC-ON system use the braking torque efficiently (less braking action) in comparison with the IC-OFF system as illustrated in the top right and bottom plots of the figure. The ESP braking activations of the IC-

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ON system only triggers the ABS braking action to avoid to large oversteer tendency as illustrated on the top right plot of Figure 46. In addition, no braking action is performed on the front left wheel by either the IC-ON and IC-OFF systems. Finally, it can be concluded that a simple rule can avoid the conflicts between the ESP and 4WS and therefore, improve the vehicle stability on the critical driving scenario that was employed throughout this thesis.

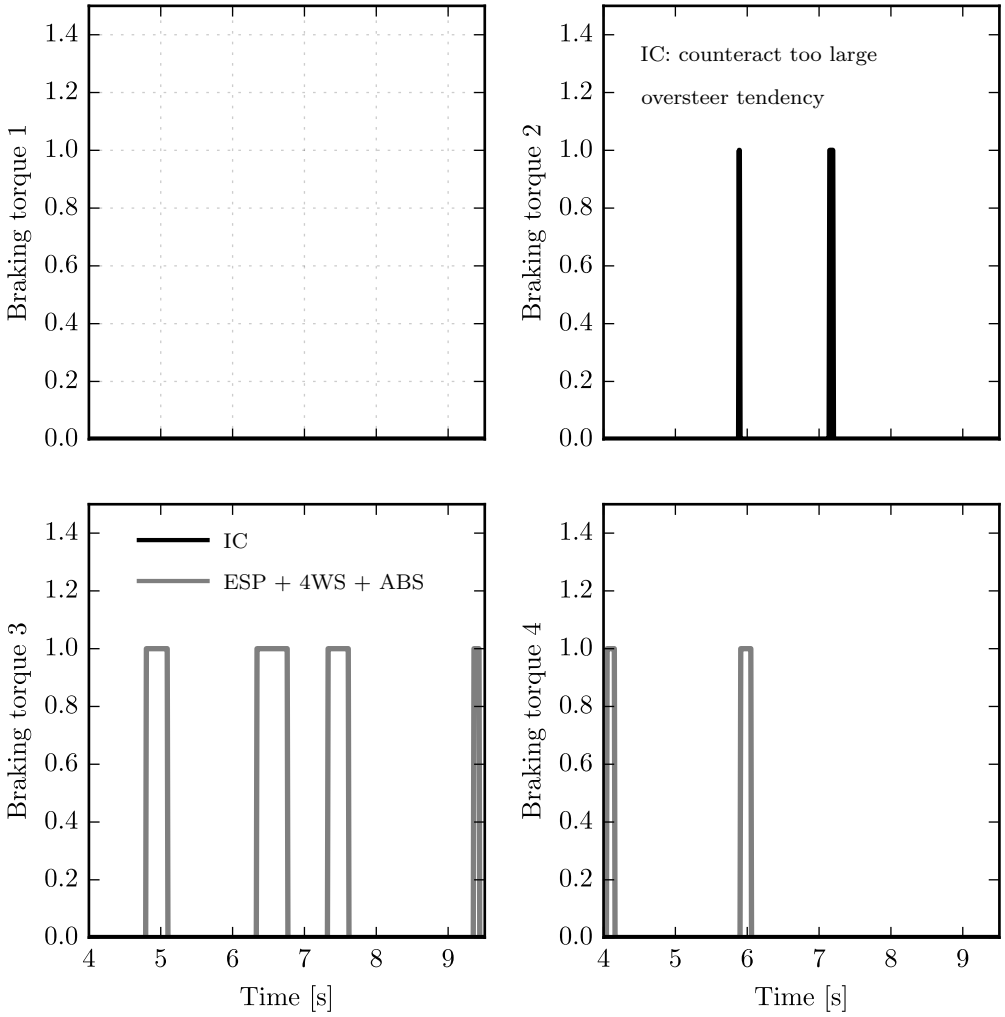

Figure 46: ESP braking activations during the avoiding maneuver. **1:** front left. **2:** front right. **3:** rear left. **4:** rear right. IC-ON (black line), IC-OFF (gray line).

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