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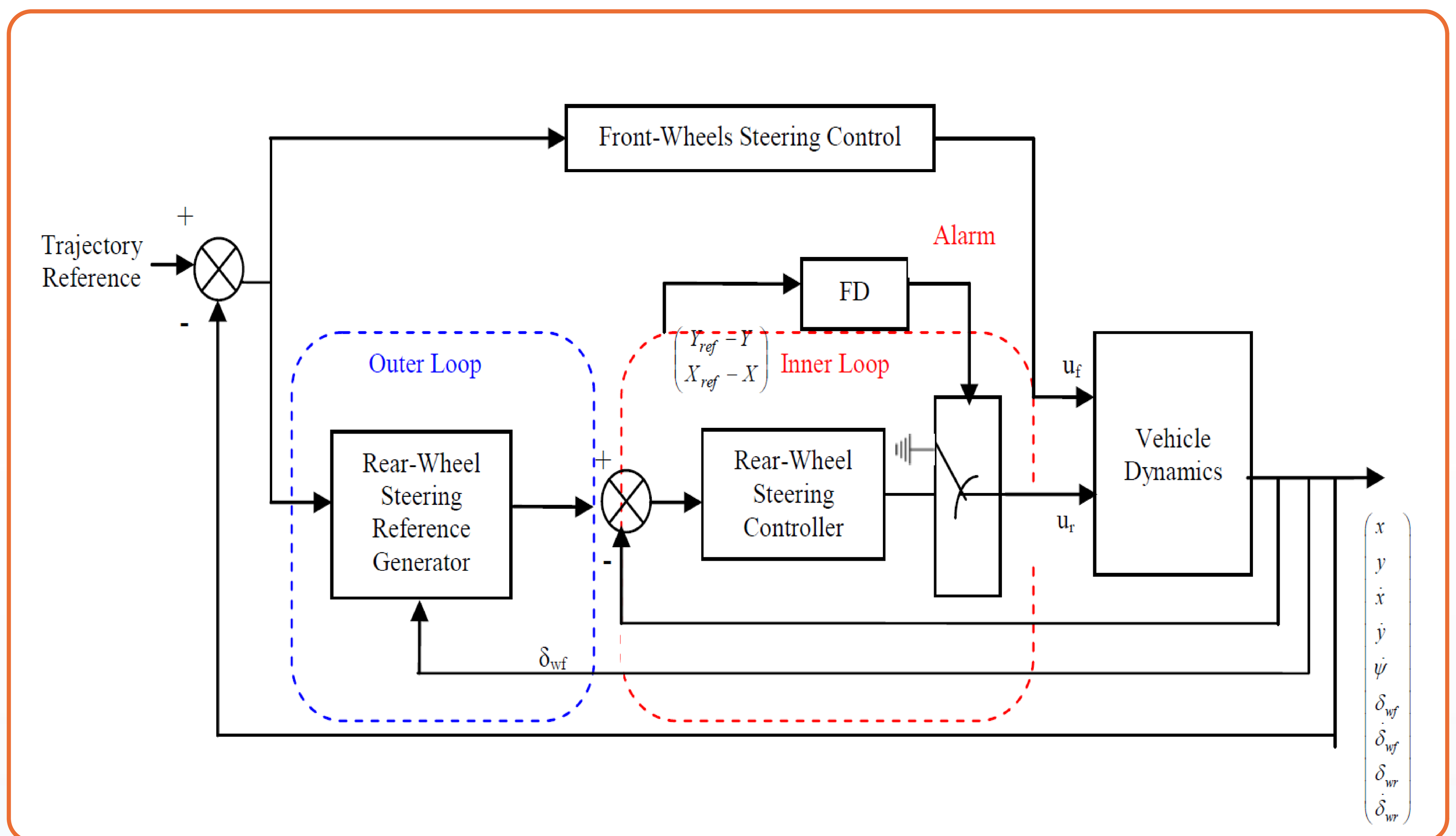
Active Fault Tolerant Decentralised Control Strategy for 2WS4WD vehicles

Objectives

➢To elaborate a control law that preserves the path tracking of autonomous 2WS4WD electrical vehicle in presence of actuator faults.
➢To test and to validate the control law on a vehicle dynamic model co-simulated by CarSim and Matlab-Simulink softwares.

Introduction

Existing strategies dealing with the control of 2WS4WD vehicles are mostly based on centralized control. When applying a centralized control strategy, the system is viewed as a whole: an algorithm is used to compute all system inputs. The disadvantage of this strategy is the necessity to redesign the entire control law when a single component is faulty. This is not the case for a decentralized control strategy, which gives the possibility to compensate faults by generating new references for local control loops. The initial control law is then maintained.



Global steering control system

Nonlinear Vehicle Model

The nonlinear model used to elaborate the control law is valid under the assumption of planar motion, rigid body, non-slipping tires, and considering that the two front wheels (resp. two rear wheels) turn at the same angle. These assumptions make it possible to determine the position of the rotation center using kinematic rules. The state-space model of the nonlinear vehicle dynamics, in the frame OXYZ fixed to the ground , can be written as follows:

$$\dot{X} = f(X) + g(U)$$

$$X = \begin{bmatrix} x & y & \dot{x} & \dot{y} & \psi & \delta_{wf} & \dot{\delta}_{wf} & \delta_{wr} & \dot{\delta}_{wr} & \dot{\theta}_1 & \dot{\theta}_2 & \dot{\theta}_3 & \dot{\theta}_4 \end{bmatrix}^T$$

$$U = \begin{bmatrix} u_f & u_r & u_1 & u_2 & u_3 & u_4 \end{bmatrix}^T$$

and $f(X)$ and $g(U)$ are expressed as follows:

$$f(X) = \Big(\sqrt{\dot{x}^2+\dot{y}^2}\cos(\psi) \quad \sqrt{\dot{x}^2+\dot{y}^2}\sin(\psi) \quad -(\dot{x}^2+\dot{y}^2)\sin(\psi)\frac{tan(\delta_{wf})+tan(\delta_{wr})}{L}$$

$$(\dot{x}^2+\dot{y}^2)\cos(\psi)\frac{tan(\delta_{wf})+tan(\delta_{wr})}{L} \quad \frac{\sqrt{\dot{x}^2+\dot{y}^2}\,(tan(\delta_{wf})+tan(\delta_{wr}))}{L}$$

$$\dot{\delta}_{wf} \quad \dot{\delta}_{wr} \quad \frac{-B_f\dot{\delta}_{wf}}{J_f} \quad \frac{-B_r\dot{\delta}_{wr}}{J_r} \quad \frac{-f_1\dot{\theta}_1+F_{x1}R\cos(\delta_{wf})+F_{y1}R\sin(\delta_{wf})}{J_1}$$

$$\frac{-f_2\dot{\theta}_2+F_{x2}R\cos(\delta_{wf})+F_{y2}R\sin(\delta_{wf})}{J_2} \quad \frac{-f_1\dot{\theta}_1+F_{x3}R\cos(\delta_{wr})+F_{y3}R\sin(\delta_{wr})}{J_3}$$

$$\frac{-f_1\dot{\theta}_1+F_{x4}R\cos(\delta_{wr})+F_{y4}R\sin(\delta_{wr})}{J_4}\Big)^T$$

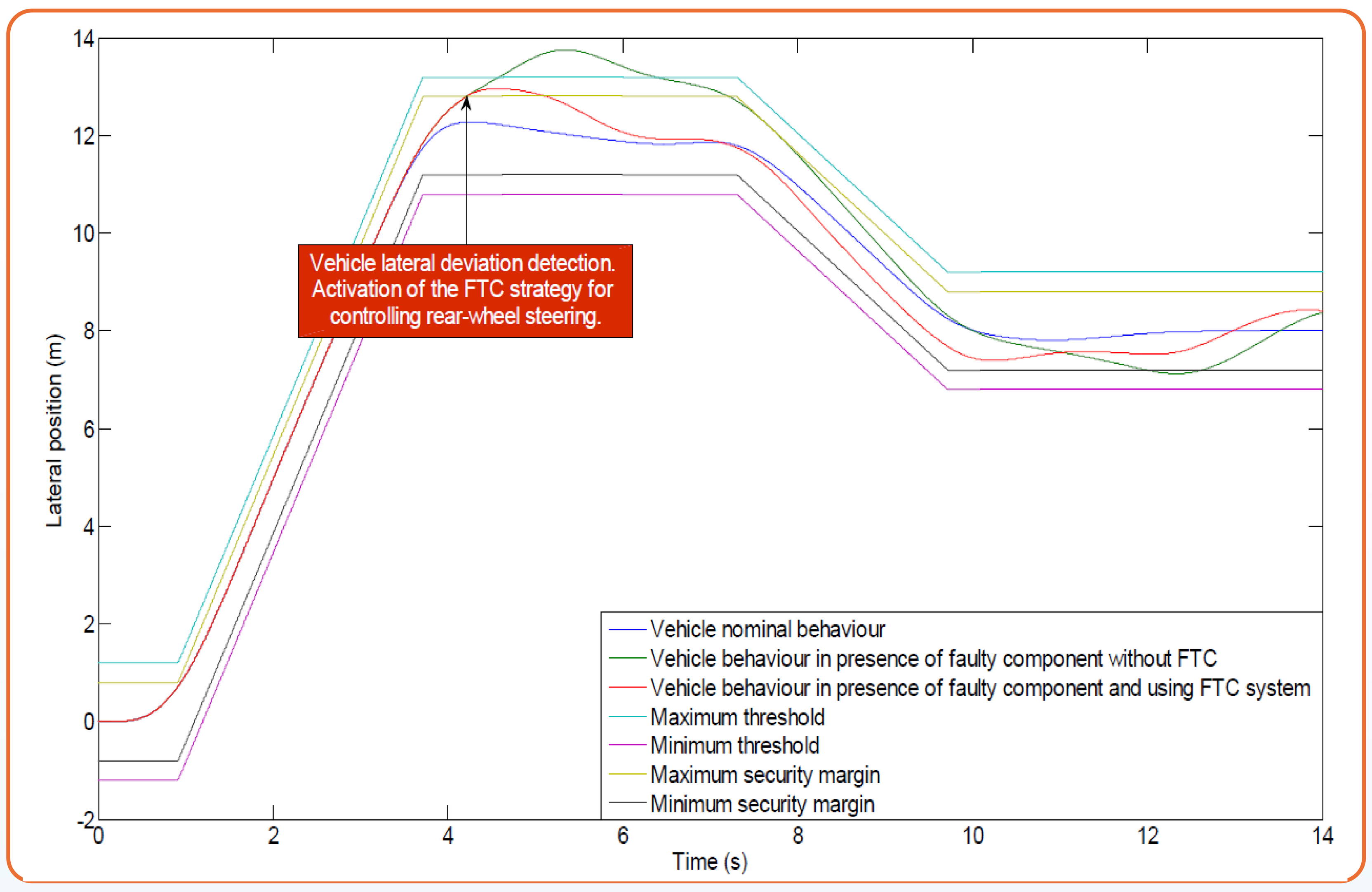
$$g(U) = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 & 0 & 0 & \frac{u_f}{J_f} & \frac{u_r}{J_r} & \frac{u_1}{J_1} & \frac{u_2}{J_2} & \frac{u_3}{J_3} & \frac{u_4}{J_4} \end{pmatrix}^T$$

Control Law

Outer Loop: The desired rear-wheel steering angle is computed in two steps. In the first step, we determine the condition that the vehicle's yaw rate has to satisfy in order to obtain the desired vehicle tracking performances. In the second step, we compute the rear-wheel steering angle necessary to obtain the vehicle's yaw rate that satisfies the condition determined in the previous step.

Inner Loop: After computing the desired rear-wheel steering position δwrdes in the outer loop, we compute the control input ur needed to track this reference. For this purpose, we will use the backstepping technique, which is a recursive control method. First, we choose a subsystem from the considered vehicle's lateral behavior model, for which we construct a virtual control law. Then, the design is extended in several steps by adding subsystems to the considered model until we obtain a control law for the full system. Along with the control law, Lyapunov functions are successively constructed in each step.

Simulation Results



Vehicle lateral behaviour when performing a double lane-change manoeuvre

Conclusion

An active fault tolerant decentralized control strategy is developed for a 2WS4WD autonomous vehicle. We demonstrate that this strategy can ensure the vehicle's lateral stability in presence of an unknown actuator fault. This strategy is developed using the backstepping technique, and consists in dividing the control strategy into two loops: the outer one and the inner one. In the outer loop, the steering position needed in order to obtain the nominal vehicle performances is computed. In the inner loop, the steering actuator input is computed such as to follow the desired reference calculated in the outer loop.

References

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