Fault-Tolerant Over-Actuated Hybrid Electric Vehicles

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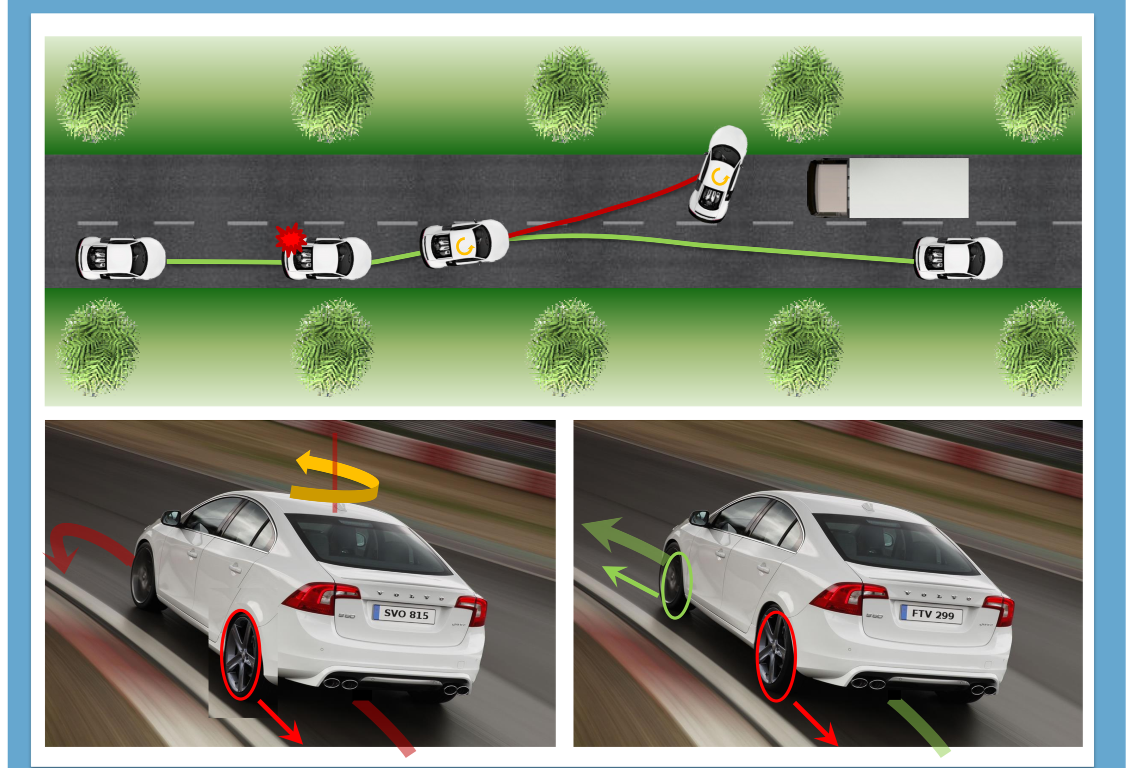
Project overview

The increase of electronics in road vehicles comes along with a broad variety of possibilities in terms of safety, handling and comfort for the users. A rising complexity of the vehicle subsystems and components accompanies this development and has to be managed by increased electronic control. More potential elements, such as sensors, actuators or software codes, can cause a failure independently or by mutually influencing each other. There is therefore a need of a structured approach to sort the faults from a vehicle dynamics stability perspective. This project tries to solve this issue by suggesting a fault classification method and fault-tolerant control strategies. Focus is on typical faults of the electric driveline and the control system, however mechanical and hydraulic faults are also considered. During the work, a broad failure mode and effect analysis has been performed and the faults have been modelled and grouped based on the effect on the vehicle dynamic behaviour. A method is proposed and evaluated, where faults are categorized into different levels of controllability, i.e. levels on how easy or difficult it is to control a fault for the driver, but also for a control system. Further, fault-tolerant control strategies are suggested that can handle a fault with a critical controllability level. Two strategies are proposed and evaluated based on the control allocation method and an electric vehicle with typical faults. It is shown that the control allocation approaches give less critical trajectory deviation compared to a regular ESC algorithm, thus leading to improved traffic safety.

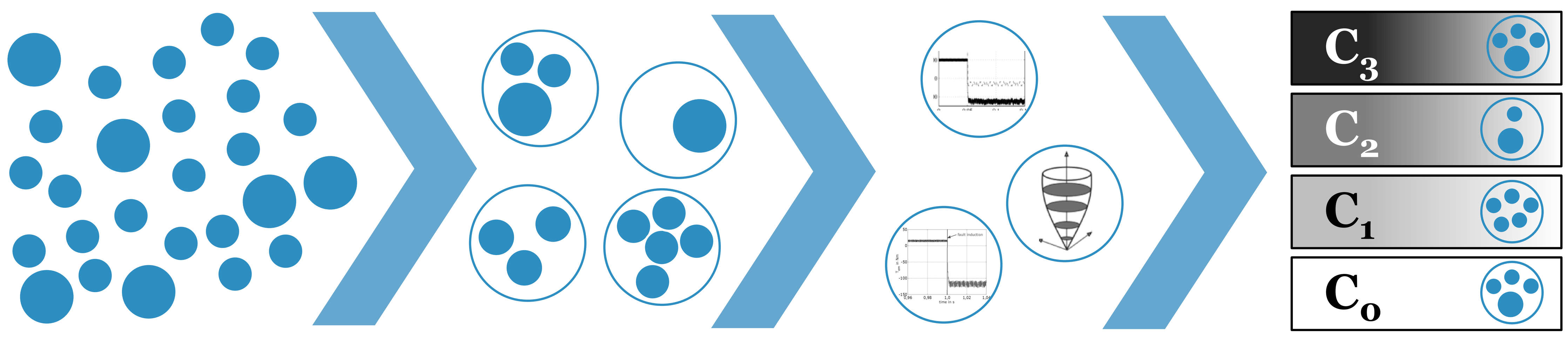
Example of a fault during driving



A yaw torque will be introduced in the vehicle without fault tolerant control. This results in a counter clockwise turning in of the vehicle. Due to the reduction of side forces on the rear axle, the under-steering behaviour changes to a over-steering behaviour. The fault can lead to loss of vehicle stability.

A vehicle with integrated fault tolerant control is able to detect and isolate the fault. It allocates counteracting forces on the wheels to compensate for the occurring yaw torque. The vehicle directional stability and its speed is preserved, increasing safety for passengers and surrounding traffic.

Faults and their influence on the dynamic behaviour of electric vehicles



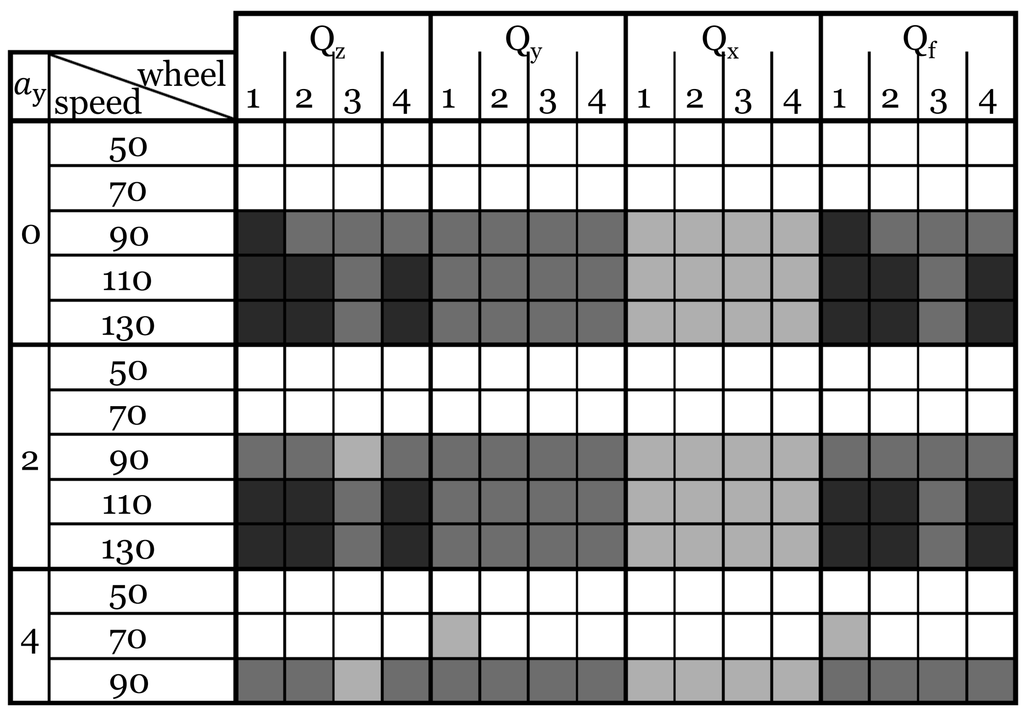
600+ faults on component level were grouped according to their effect on the vehicle behaviour.

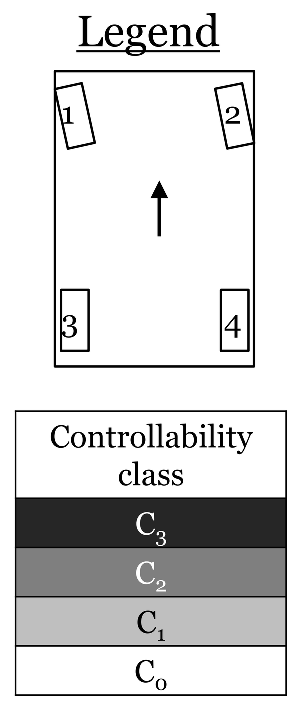
Detailed modeling of the 31 fault groups in the according sub-systems of the vehicle.

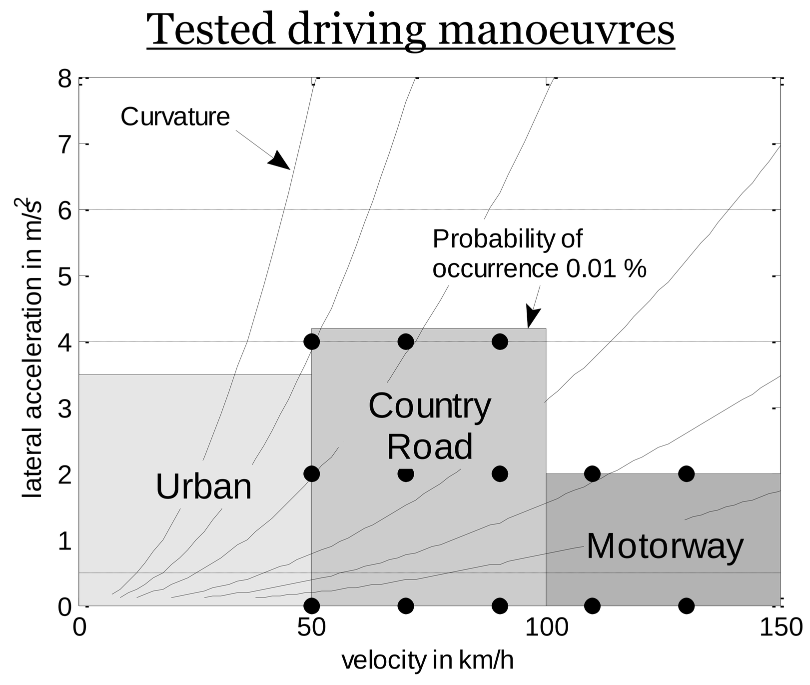
Evaluated according to objective vehicle handling criteria and ranked in the fault classification.

4 controllability classes to indicated the severity of a fault in accordance with ISO 26262.

A fault classification method is developed to indicate the severity of a fault in a vehicle (above). Fault classification results for an inverter shutdown (below), shows a clear tendency for higher severity during high velocities, thus in the field-weakening range. Thereby, the vehicle stability index Q_z has the highest influence on the fault classification. The lane keeping index Q_y as well as the collision avoidance index Q_x have less significance. At motorway speeds, the controllability class reaches C_3 for all wheel locations but the third.





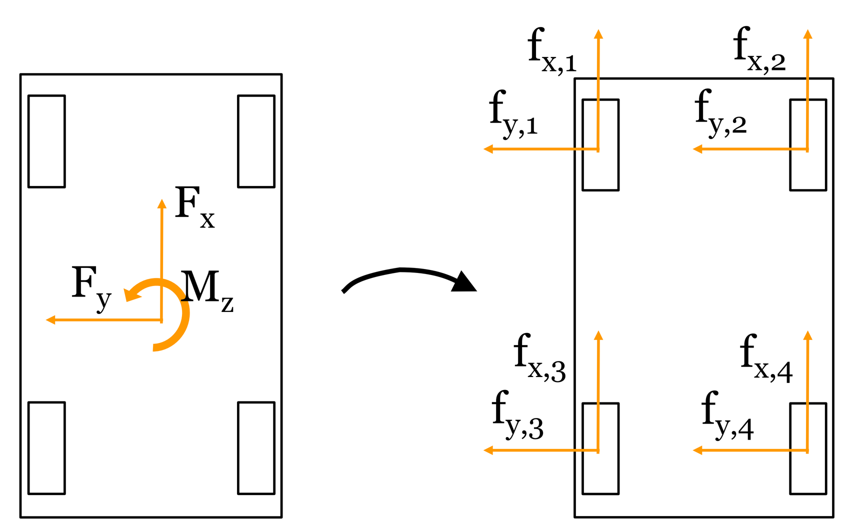


Fault-tolerant control strategies for fault handling

The chosen control strategy is control allocation. It is able to generate useful solutions for faulty situations. Control allocation is a method that solves a mathematically under-determined problem. This occurs as soon as the number of controllable actuators is higher than the number of degrees of freedom, i.e. as it is in case of an over-actuated vehicle. The forces of the vehicle are distributed to the tyre forces as seen in the figure below.

Principle of control allocation

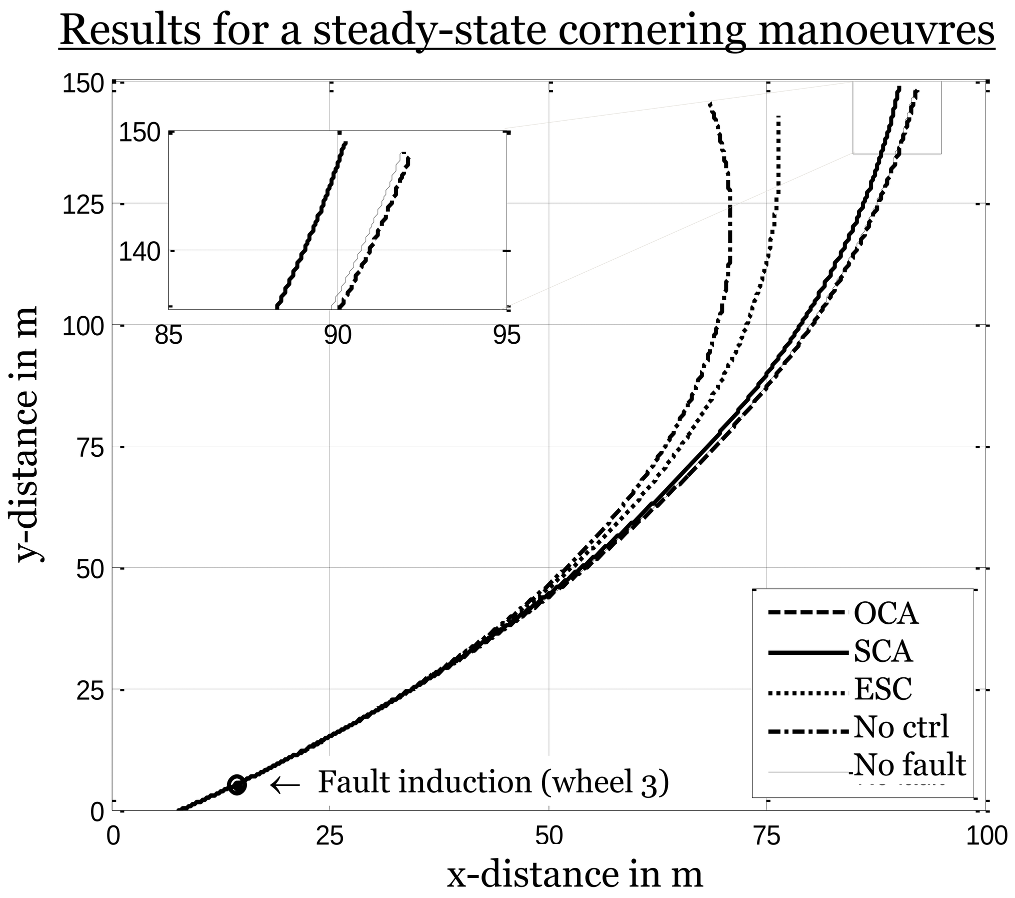
- Allocates the vehicle forces to the tyre forces.
- Under-determined mathematical problem.
- Optimisation and analytical approach available.



3 global forces (in the center of gravity of the vehicle)

8 local forces (in x- and y-direction of each wheel)

Results for a steady-state cornering manoeuvres



Legend:
OCA – optimised control allocation
SCA – simplified control allocation
ESC – electronic stability control
No ctrl – uncontrolled vehicle