Towards a Dependable Model-Data Inspired Paradigm for Internet of Vehicles

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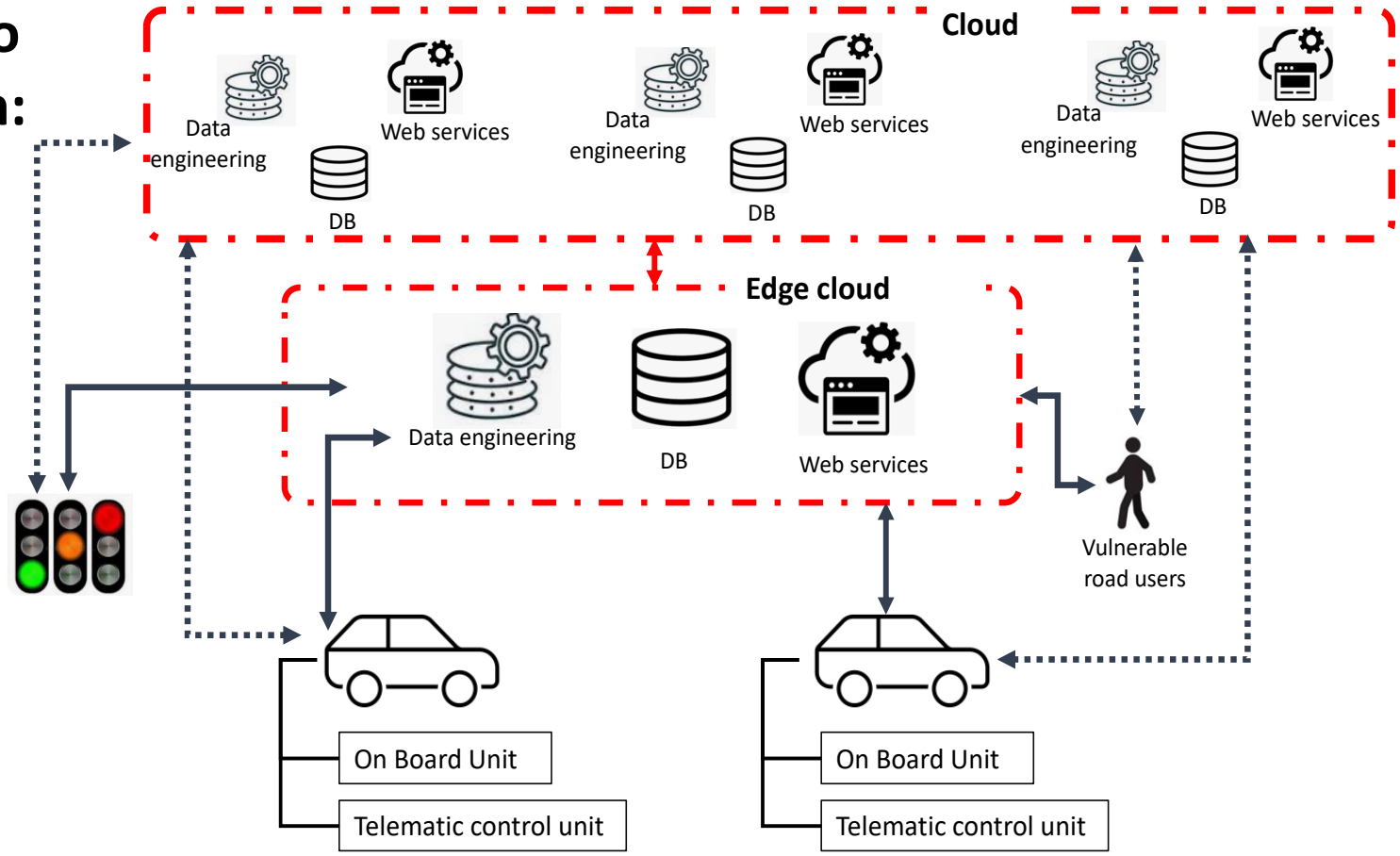
Outline

- Internet of Vehicles
- Vehicle Control Systems and Recent Progresses
- Model-Data Inspired VDC
- Towards Dependable Model-Data Inspired IO-EV

Internet of Vehicles Ecosystem

Vehicles slowly are integrated into the IoT system to bring services in:

- Traffic-flow management
- Road-intersection management
- Vehicle customization
- Third party applications
- No safety-critical applications
- No application for high-fidelity virtual vehicle testing and validation



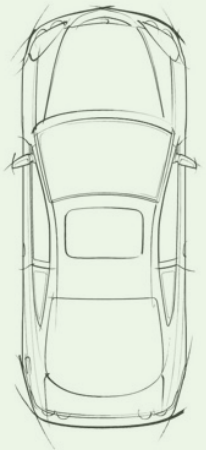
Holistic Vehicle Control System and Automated Driving

Perception layer for ADAS and automated vehicles		
Cameras	Short range radars	LIDARS
GNSS	Long range radars	….

Vehicle Control System

Vehicle Stock Systems

- IMU
- Wheel speed
- Brake pressure
- Motor torque
- Steering wheel angle
- Suspension height
- …



Control Systems

- Traction control
- Torque vectoring
- Active steering
- Differential braking
- Throttle control
- Active aerodynamics
- …

Firewall

Internet of Vehicles		
Vehicle to Vehicle	Vehicle to Infrastructure	HD Maps
Road conditions	Traffic information	…

Progresses in VDC* Systems

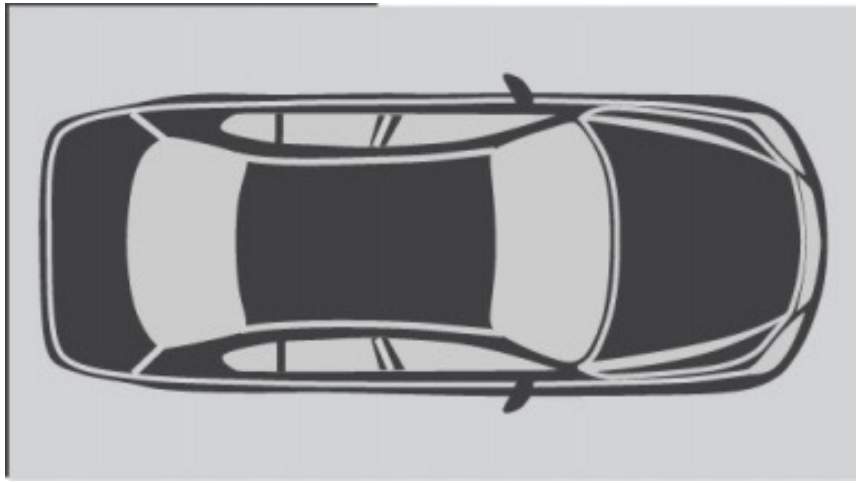
- Universal VDC Systems
- Agent-Based VDC Systems
- Model-Data Inspired VDC Systems
- Dependable IoV for VDC Systems

* In this talk, VDC includes both control and estimation systems.

Holistic vs. Subsystem-based VDC Systems

Control Systems

- Traction control
- Torque vectoring
- Active steering
- Differential braking
- Throttle control



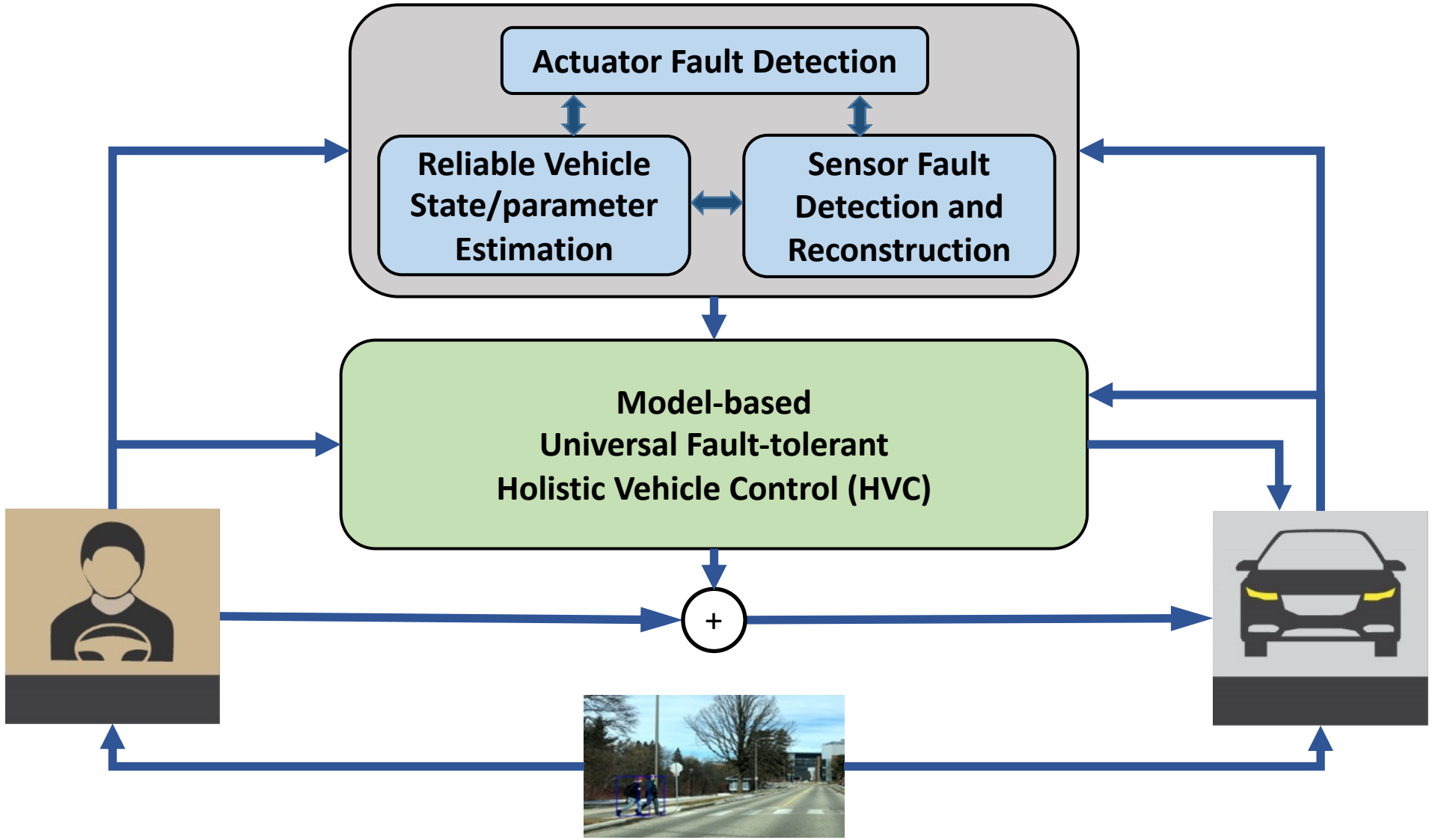
Control Systems

- Power management
- Suspension control
- Transmission control
- eLSD control
- Active aerodynamics

General Features of Subsystem-based VDCs

- Error-based control
- Non-optimal solution
- Event-based design to have a peaceful coexistence of different controllers
- Long development time and expensive

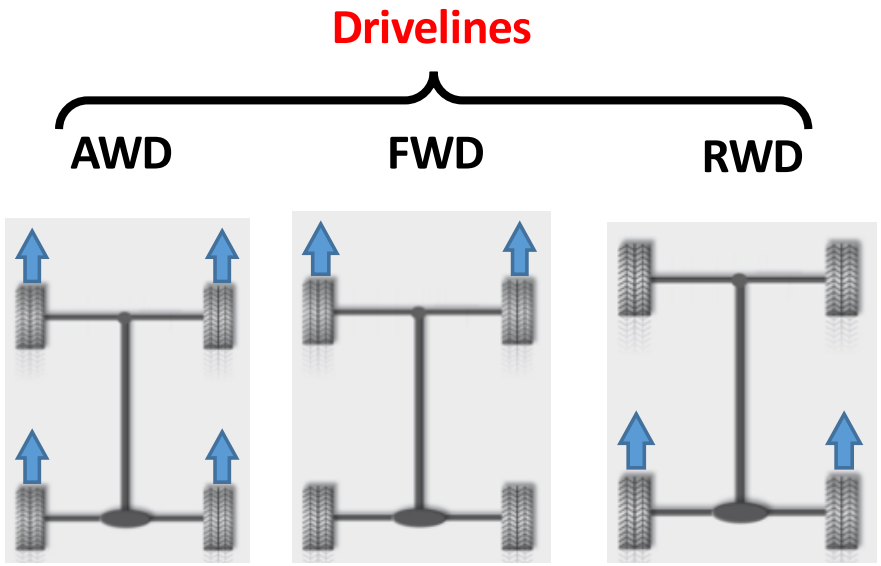
Universal Holistic Vehicle Control Structure



Universal Holistic VDC Systems

- One VDC system for any car with any control actuation topology

Any powertrain type



Performance Vehicles

SUVs

Family Cars

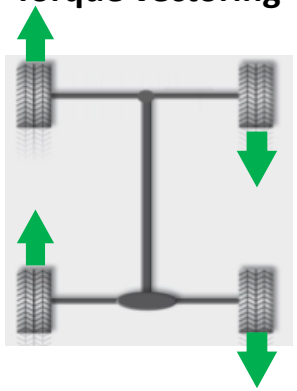
Pick up Trucks

Universal Holistic VDC Systems (cont.)

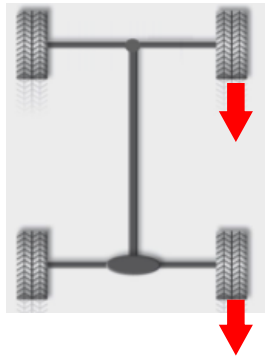
Any control actuation topology

Actuators: Traction/Brake Torque

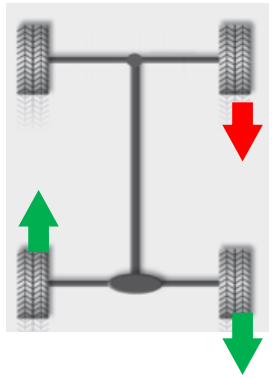
Torque vectoring



Differential Braking

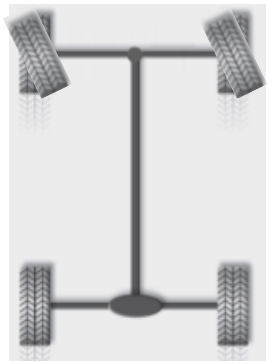


Hybrid

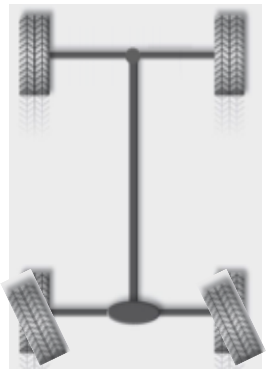


Actuators: Active Steering

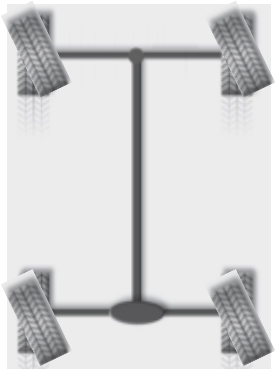
AFS



ARS



AAS



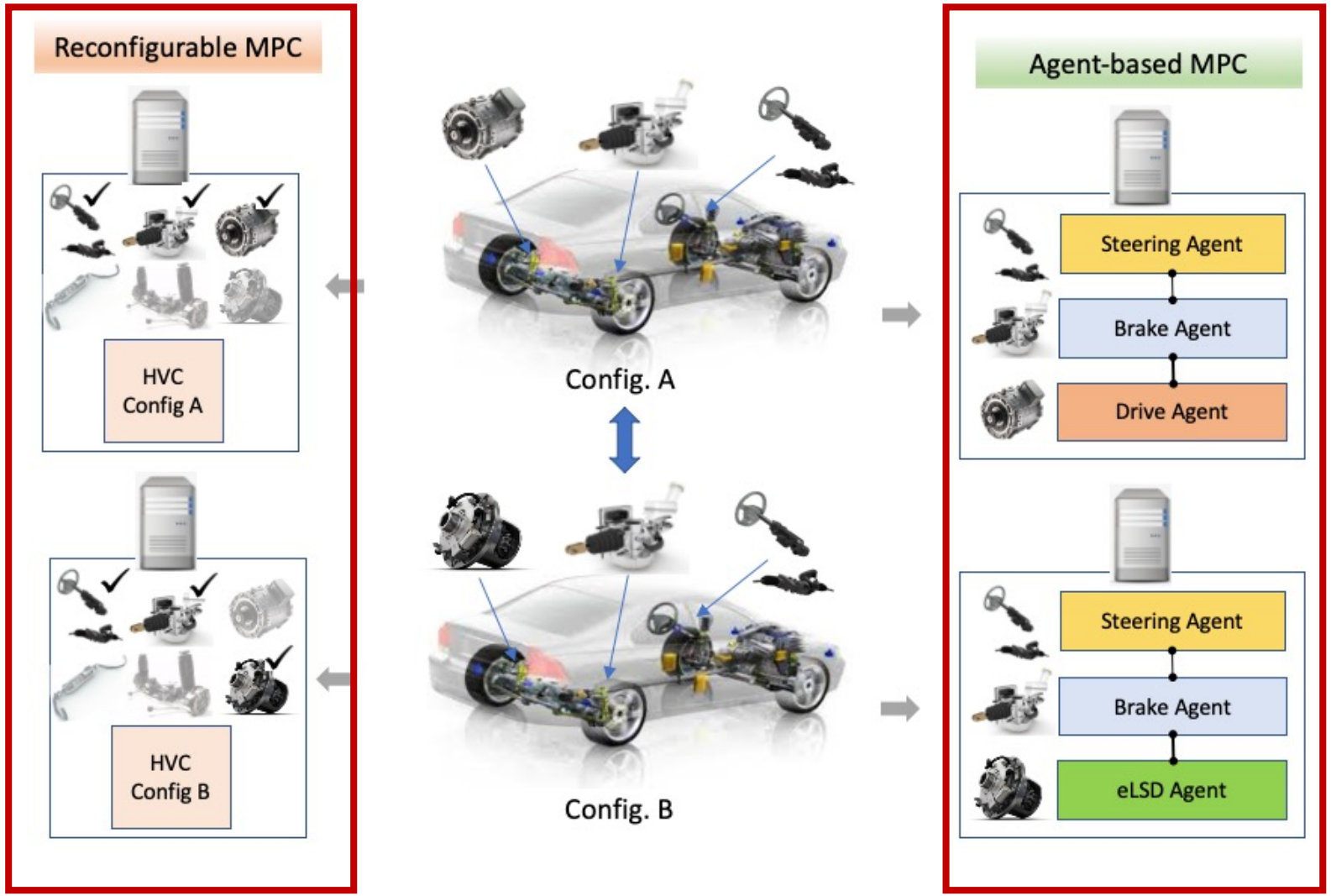
- Active Aerodynamics
- Active Roll Control

Universal Holistic VDC Systems (cont.)

Other features of Universal Holistic VDC Systems

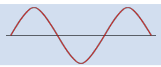
- Sensor fault detection and real time reconstruction
- Actuator fault detection and real time control action reallocation
- Handle actuator dynamics
- Embedded power management system

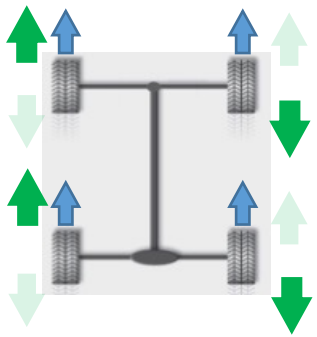
Agent-based Holistic Vehicle Control

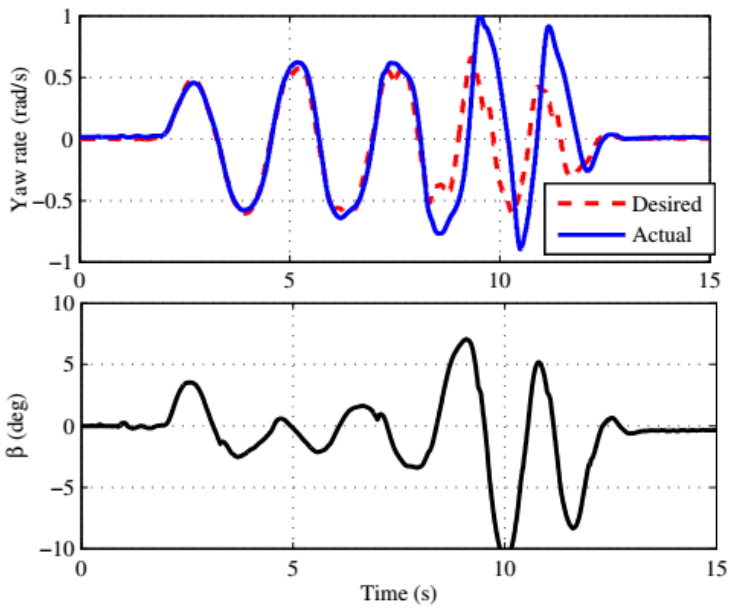


Model-based Universal Fault-tolerant HVC

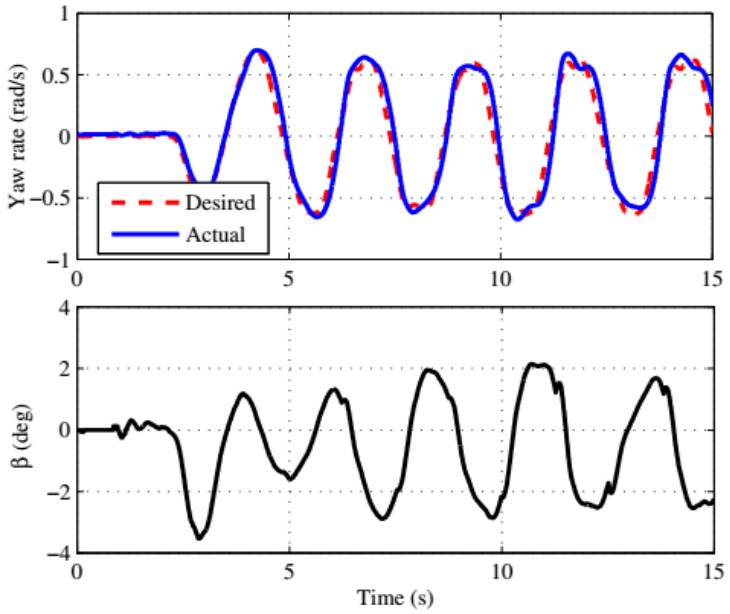
- Vehicle: Electric AWD SUV
- Control actuation: Torque Vectoring
- Test Maneuver: Slalom

Parameter	Value
Steering input	
Initial velocity	0 km/h
Accelerator pedal	Fully pressed
Road condition	Dry





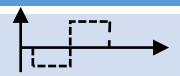
(a) Controller off.

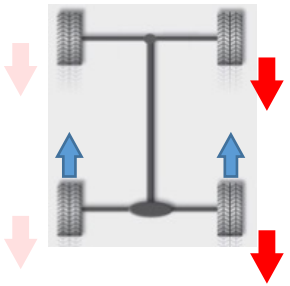


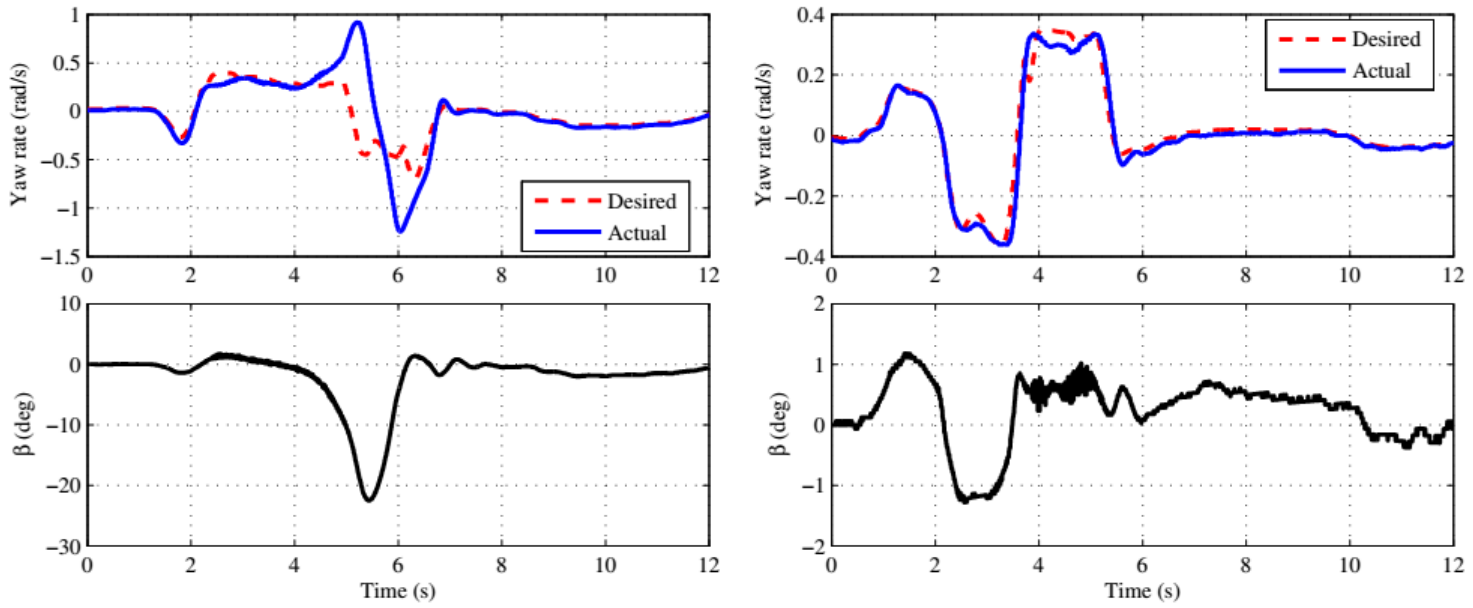
(b) Controller on.

Model-based Universal Fault-tolerant HVC

- Vehicle: Electric RWD SUV
- Control actuation: Rear Torque Vectoring and Differential Braking
- Test Maneuver: Double Lane Change

Parameter	Value
Steering input	
Initial velocity	35 km/h
Accelerator pedal	Pressed in steering
Road condition	$\mathbf{Wet}, \mu \approx 0.4$

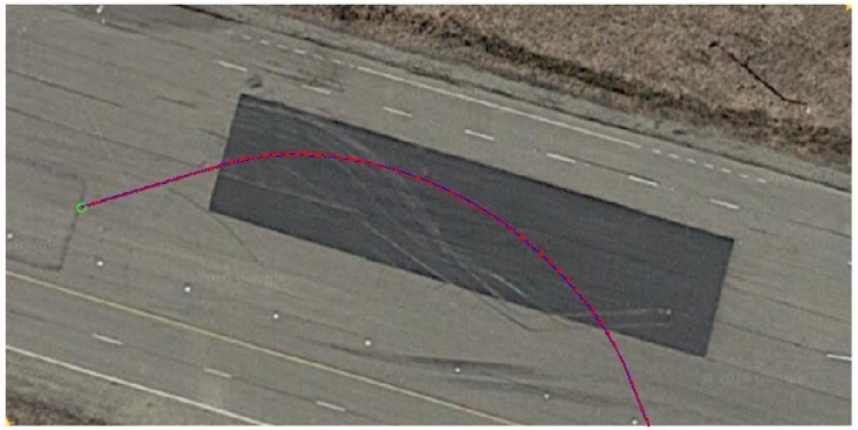


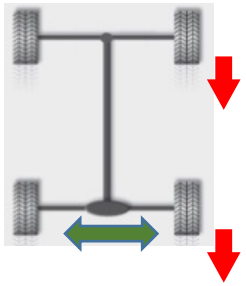


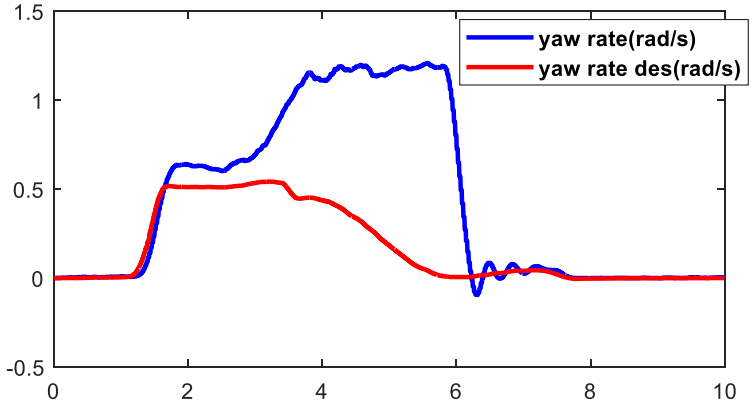
(a) Controller off. (b) Controller on.

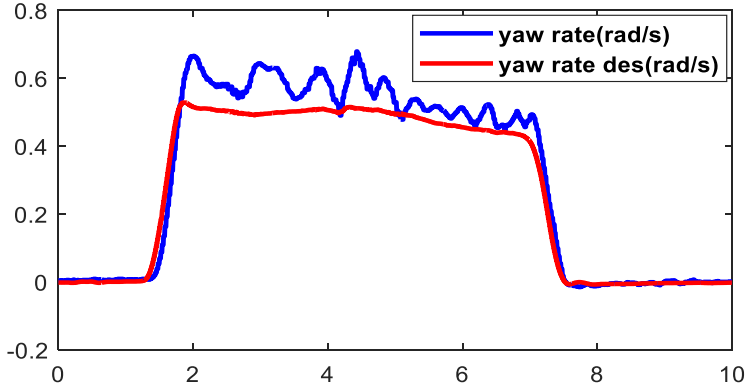
Model-based Universal Fault-tolerant HVC

- Vehicle: Production Vehicle – Cadillac CTS-V, RWD Sedan
- Control actuation: Electronic Limited Slip Differential (eLSD) and Differential Braking
- Test Maneuver: Acceleration in Turn in wet surface, $\mu \approx 0.4$









Controller Off **Controller On**

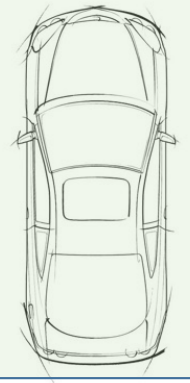
Model-Data Inspired VDC

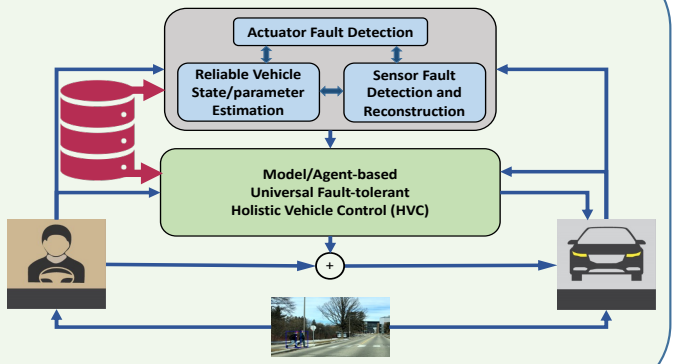
Perception layer for automated vehicles		
Cameras	Short range radars	LIDARS
GNSS	Long range radars	....

Vehicle Traditional Sensors

- IMU
- Wheel speed
- Brake pressure
- Motor/engine torque
- Steering wheel angle
- ...

HVC System





Firewall

Internet of Vehicles		
Vehicle to Vehicle	Vehicle to Infrastructure	High-resolution Map data
Road conditions	Traffic information	...

- Model-based VDC systems enhance greatly vehicle safety
- Data can be used to reduce model and road uncertainties to improve further control and estimation systems

Model-Data Inspired VDC

- Learning MPC
- Learning Agent-based MPC
- Real-Time Learning-based MPC Weight Tuning
- Holistic Vehicle Health Monitoring System

Learning MPC for HVC - Experiments

- Use of data to compensate for model errors
- Real-time learning module to learn-as-you-go
- Data management to keep only relevant data
- Authentication method to choose between model and data

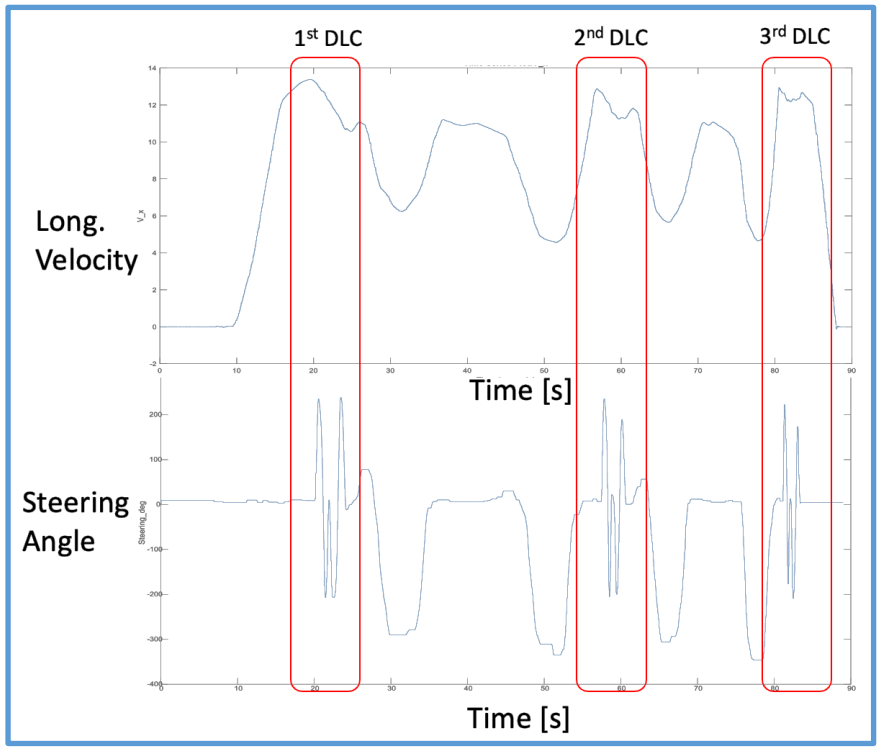
Equinox EV

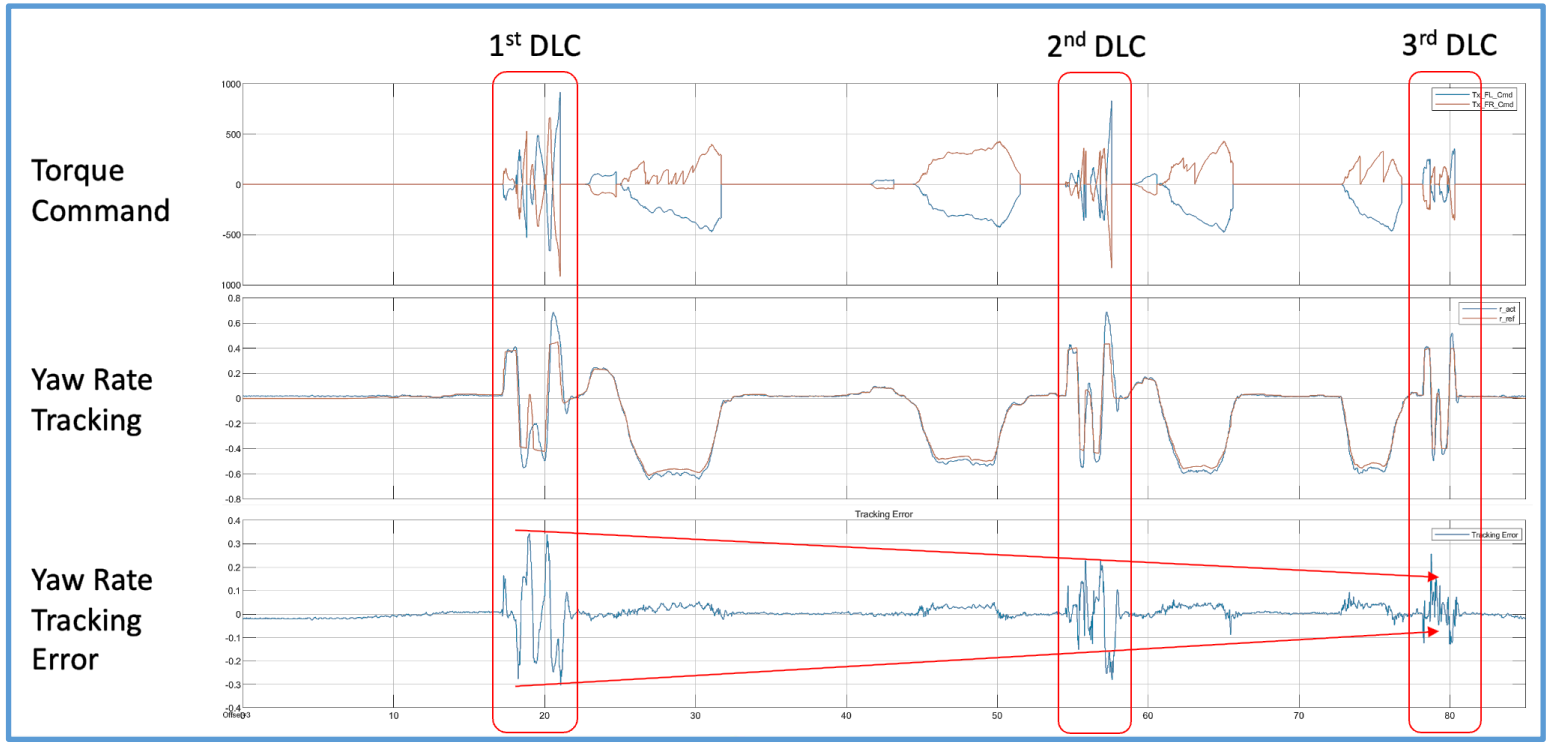
Wet Asphalt Patch

Waterloo Test track

Learning MPC for HVC - Experiments

Double Lane Change Results





Learning Agent-based MPC: Experiments

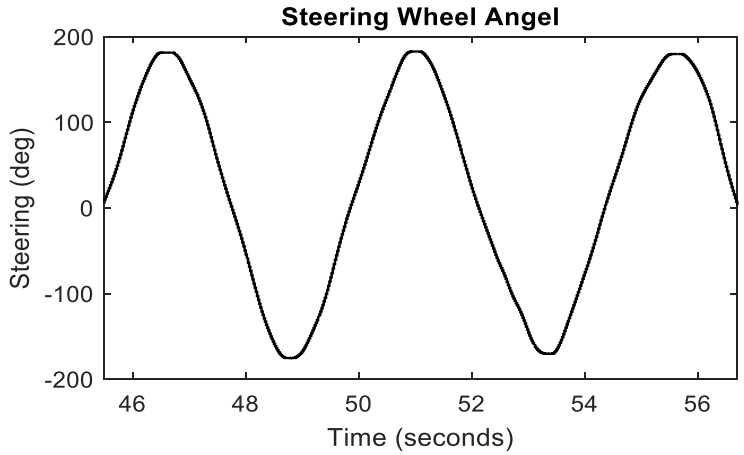
Agents:

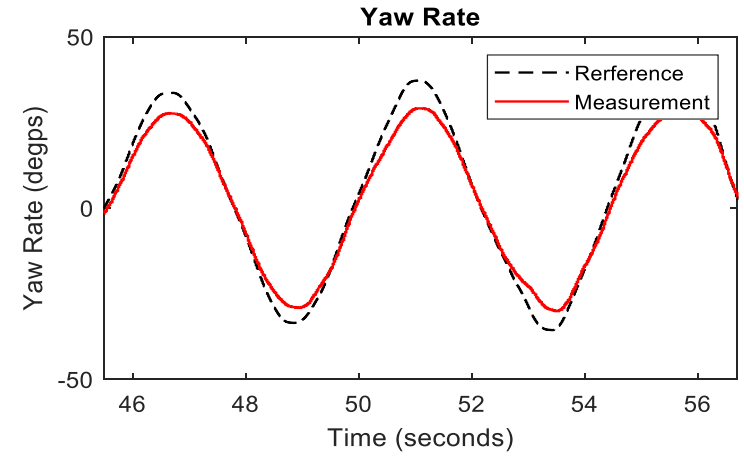
- FDT (Front Differential Torque)
- RDT (Rear Differential Torque)
- AFS (Active Front Steering)
- DT (Driver Torque)

Scenario	Agent configuration	Driving Maneuver	Vehicle Speed	Road Friction
Two Black-box Agents	• Controllable agent: RDT • White-box agent: DT • Black-box agent: FDT & AFS	Sinewaves	40 kph	dry asphalt

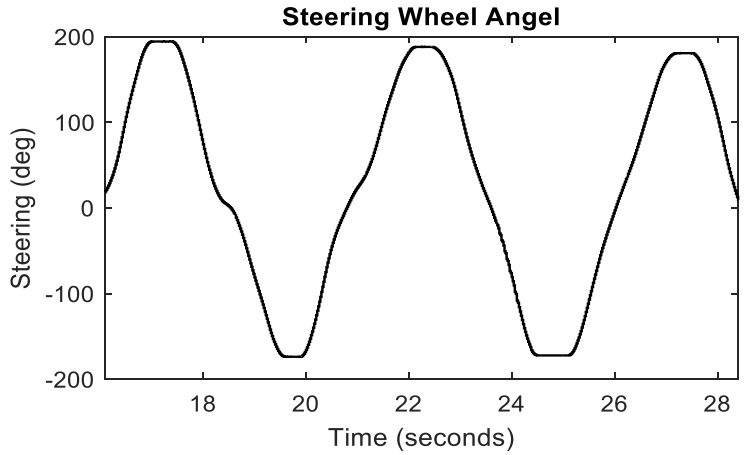
Learning Agent-based MPC: Experiments

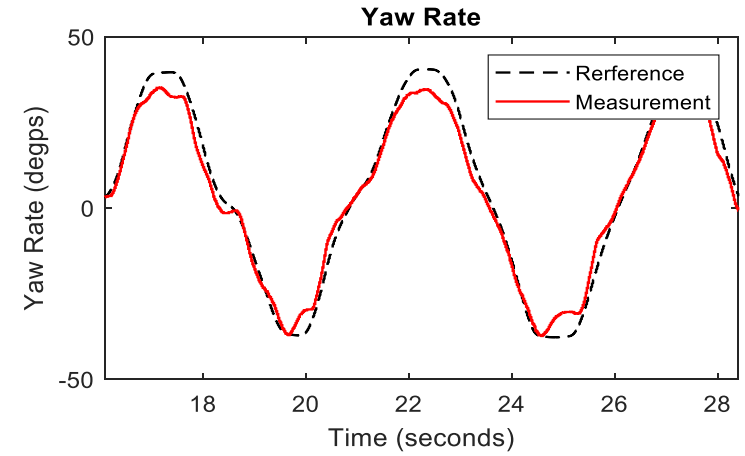
RDT, FDT and AFS are turned off



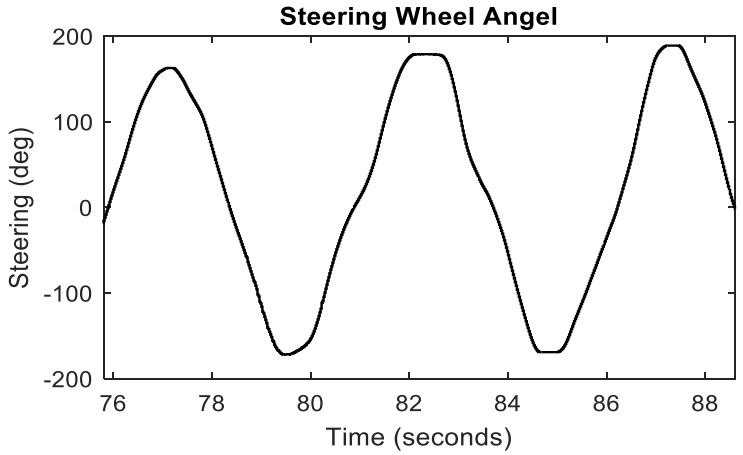


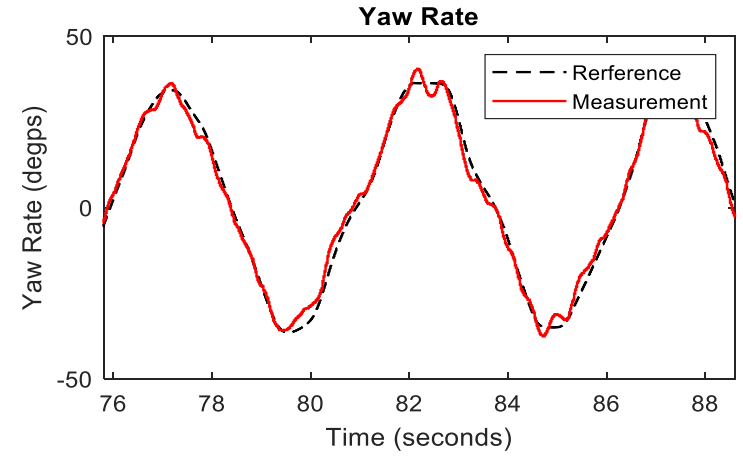
RDT, FDT and AFS are turned on; RDT controlled by AMPC



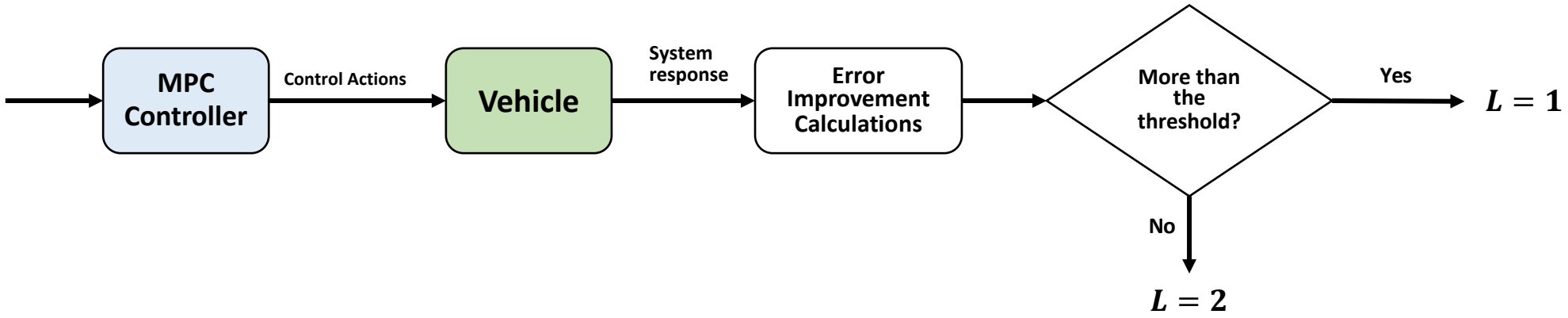


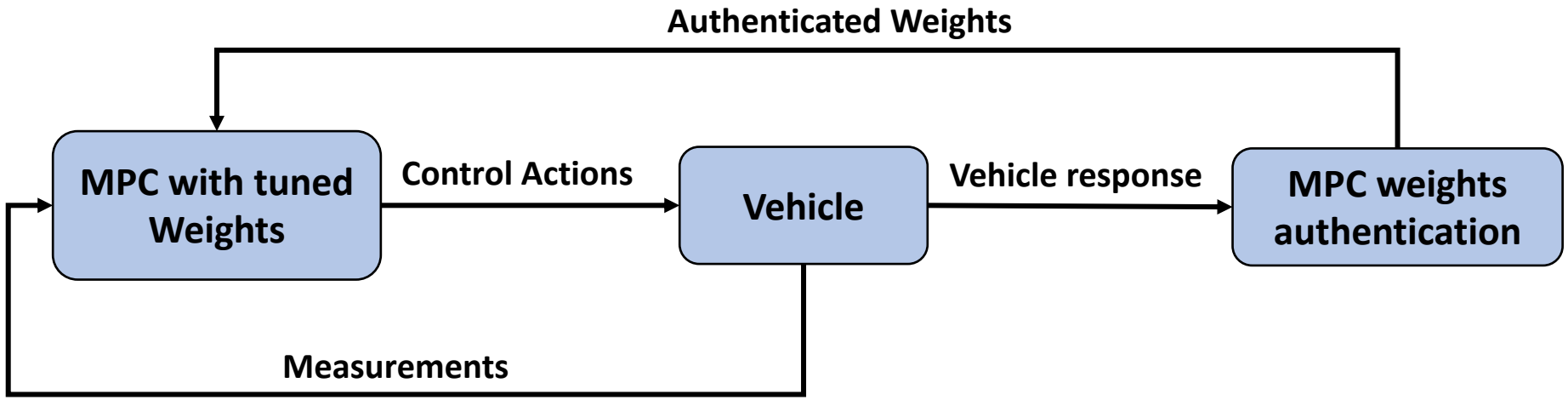
RDT, FDT and AFS are turned on; RDT controlled by LAMPC





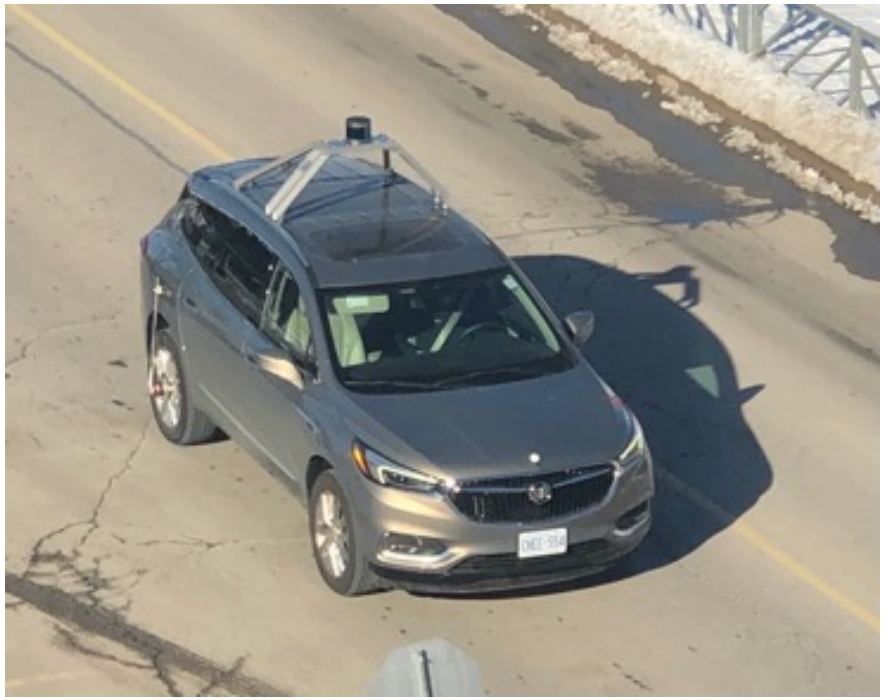
Real-Time Learning-based MPC Weight Tuning



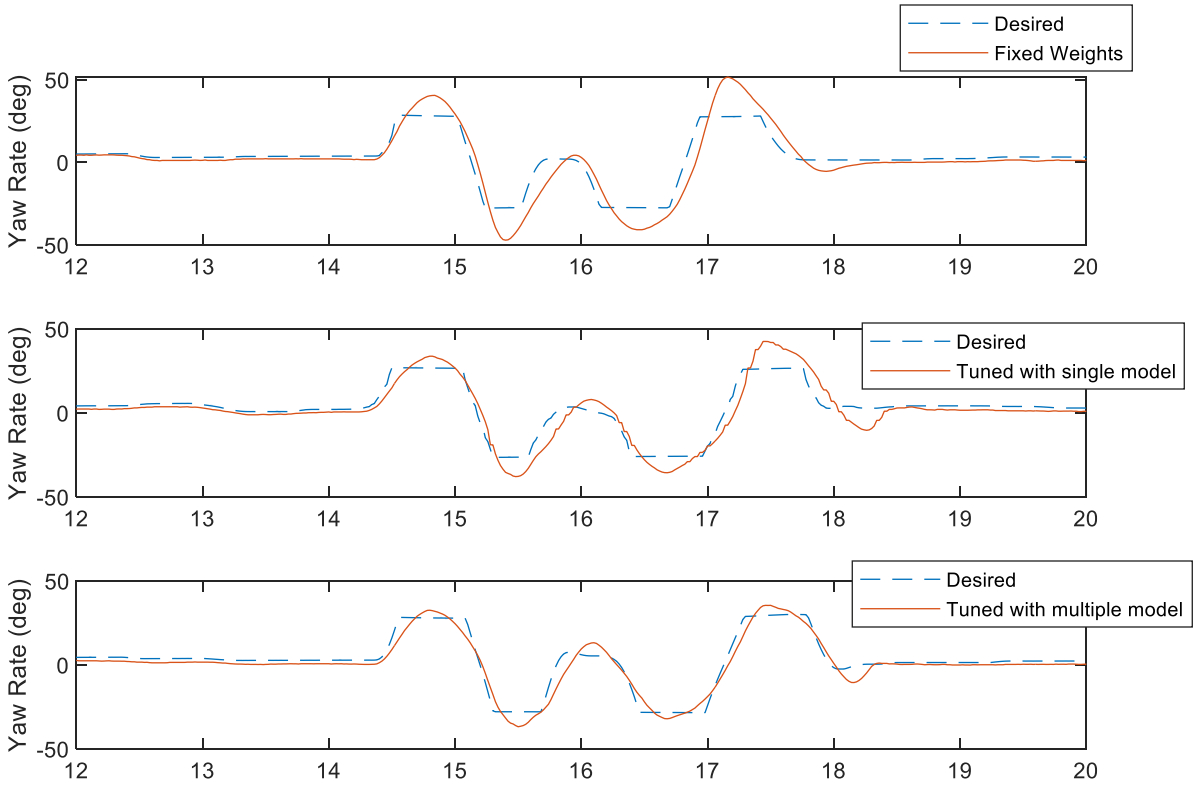


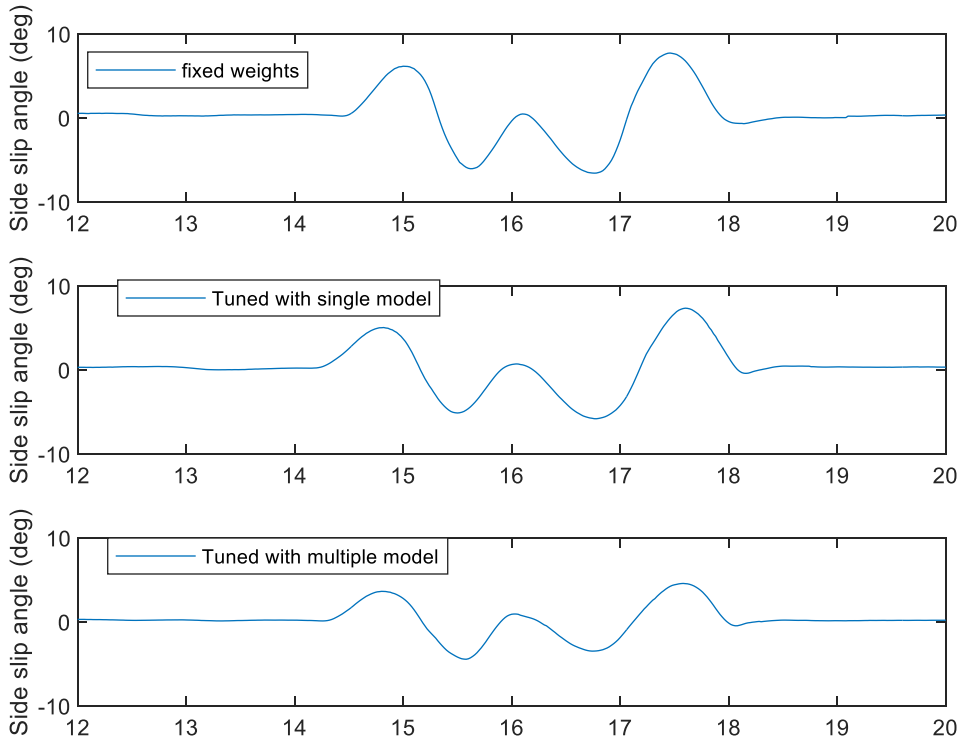
Real-Time Learning-based MPC Weight Tuning: Experiments

- Double Lane Change maneuvers
- Vehicle average speed 70 kph
- Torque vectoring control action
- Real-time weight selection



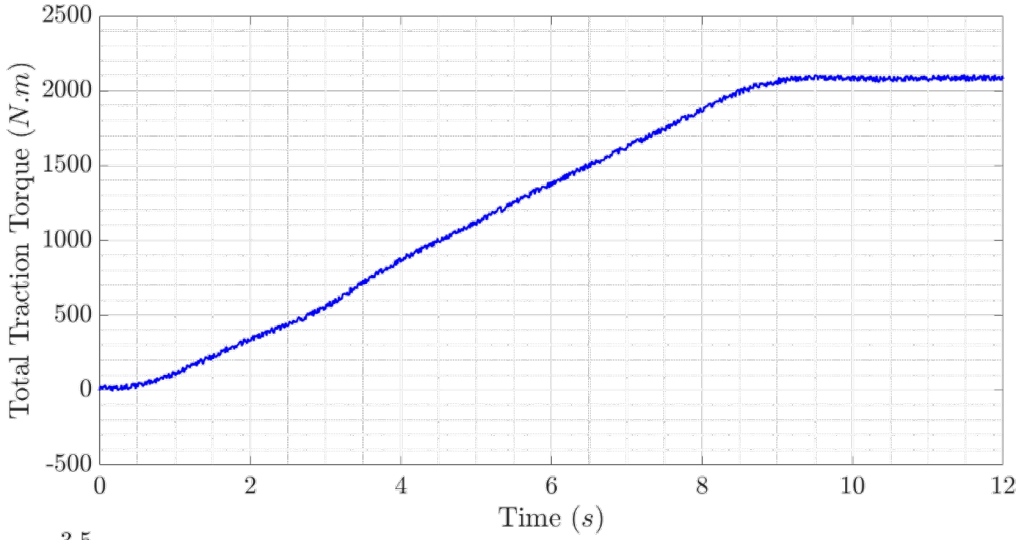
Real-Time Learning-based MPC Weight Tuning: Experiments

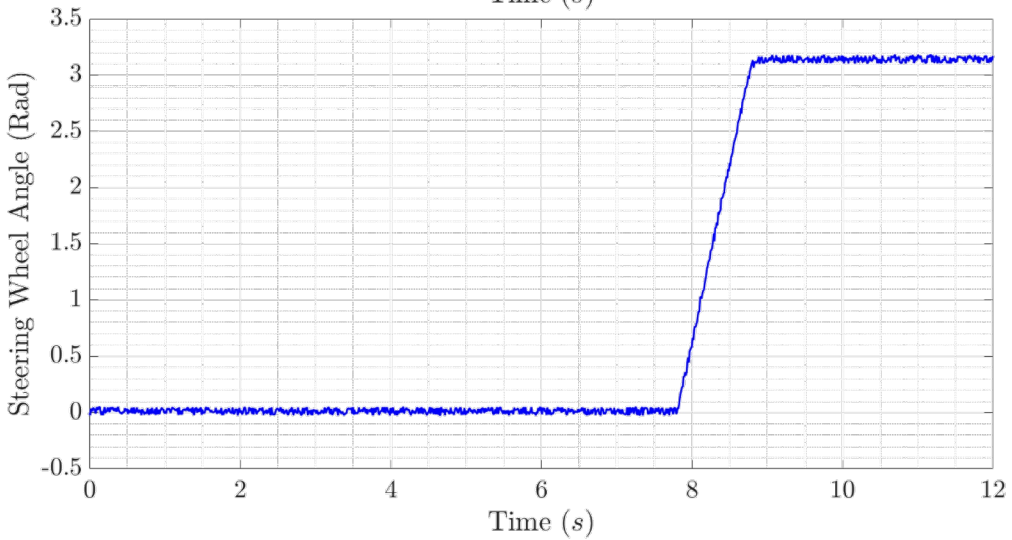




Holistic Vehicle Health Monitoring System: Experiments

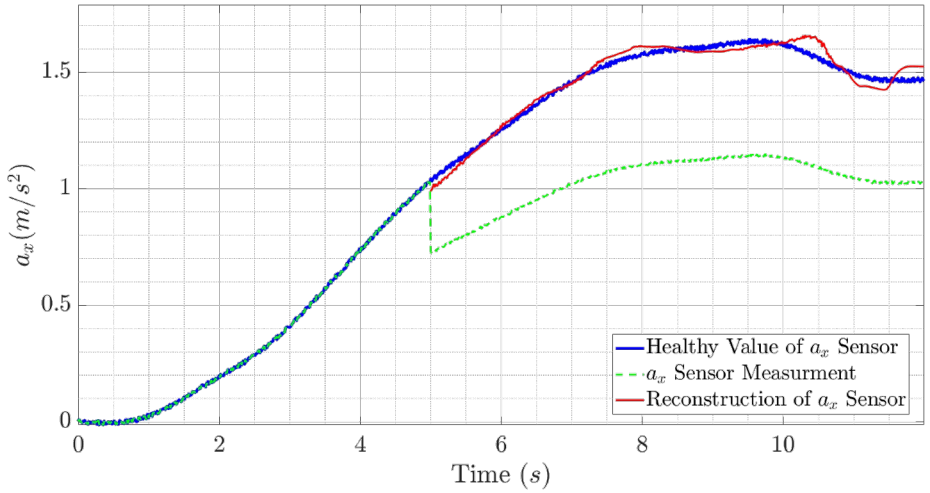
- **Acceleration-in-turn Maneuvers**



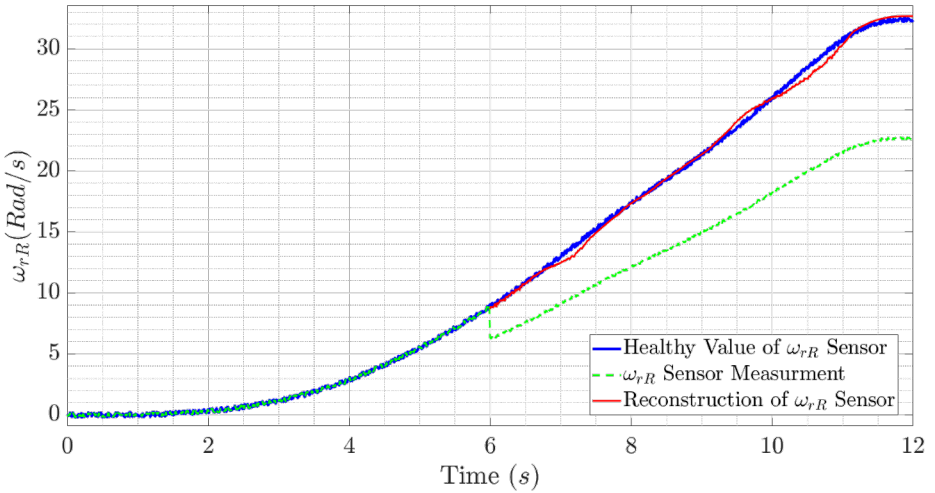


Holistic Vehicle Health Monitoring System: Experiments

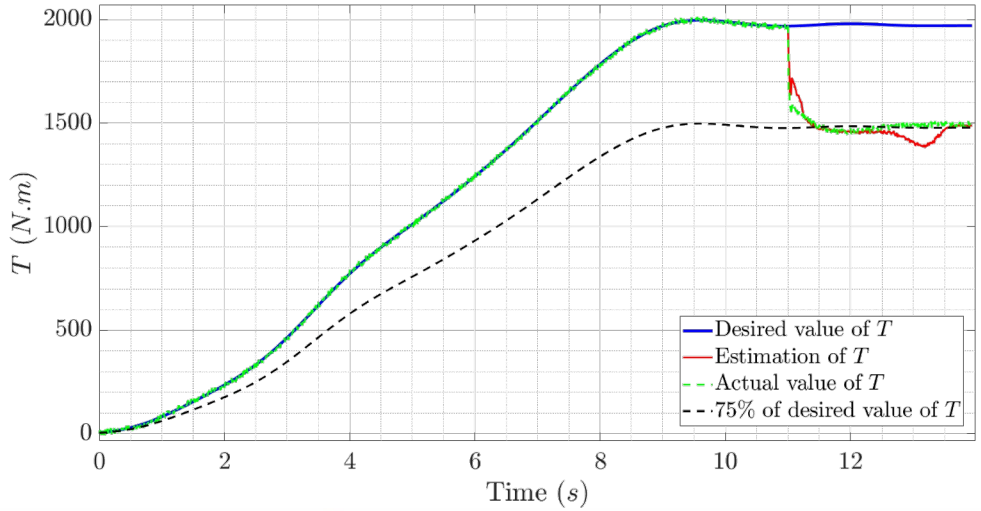
Faulty Longitudinal Acceleration Sensor



Faulty Wheel Speed Sensor



Faulty Traction Motor



Main Objectives of a Dependable IoT

- **Universal Database for IoV**
  - Type of data and normalization
  - Coherency
  - Healing
  - Resource Allocation
  - Real-time Computation Topology
- **Model-data inspired solutions for vehicle applications**
  - Vehicle Control
  - Estimation Systems
  - Health Monitoring
  - Diagnosis and Prognosis
  - Power Management
  - Real-time Perception Reliability Analysis
  - Path planning/tracking

Thank you !