CAV 7A.3.1.2 CACC Development for Cars with Different Powertrains

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OUTLINE

- Research scope / objectives
- Generic architecture
- Low level speed tracking
- High level gap regulation
- Control design
- Leader results
- CACC following results
- Conclusions

RESEARCH SCOPE / OBJECTIVES

- Extend CACC capabilities and its positive impact

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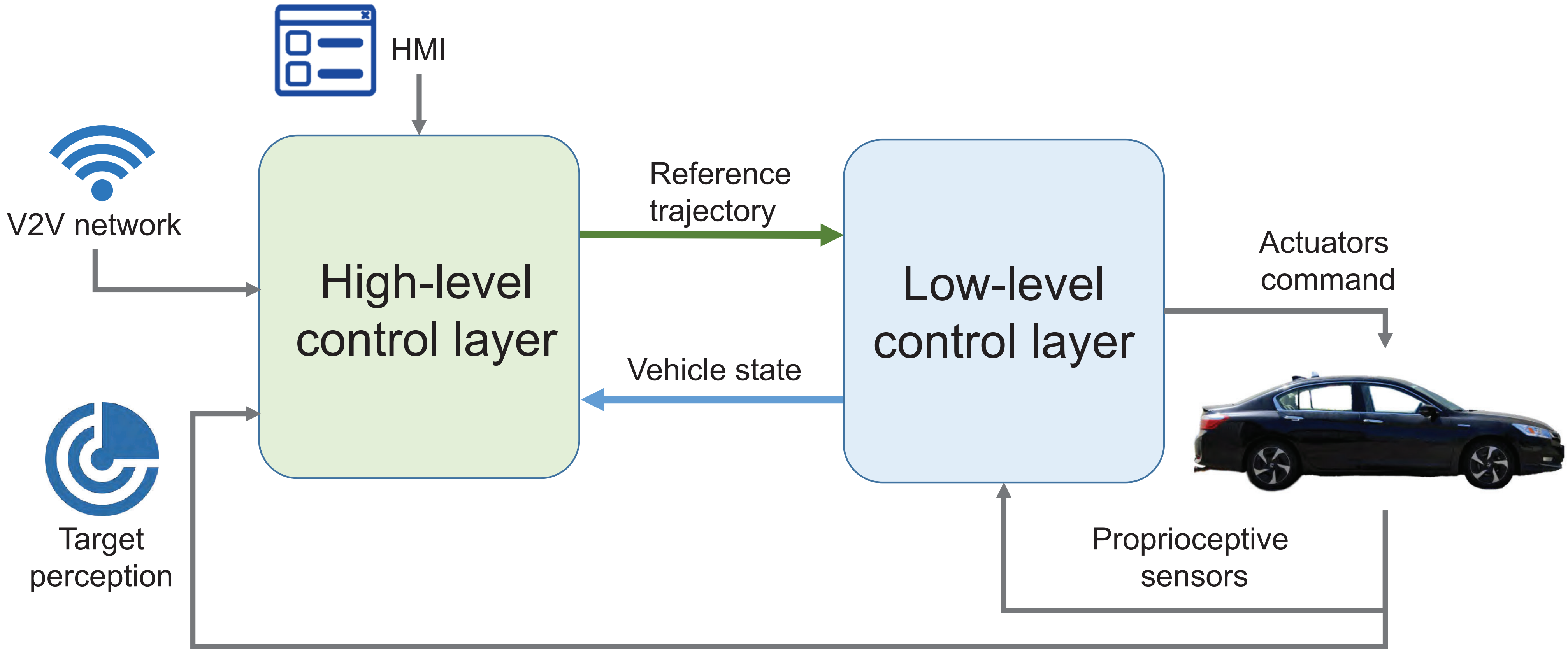
- Investigate challenges of heterogeneous CACC strings
- Design a generic architecture for all types of vehicle dynamics
- Yield a system configurable for the excepted performance
- Study best string ordering methodology
- Enhance handling of desired gap changes / cutting in or out



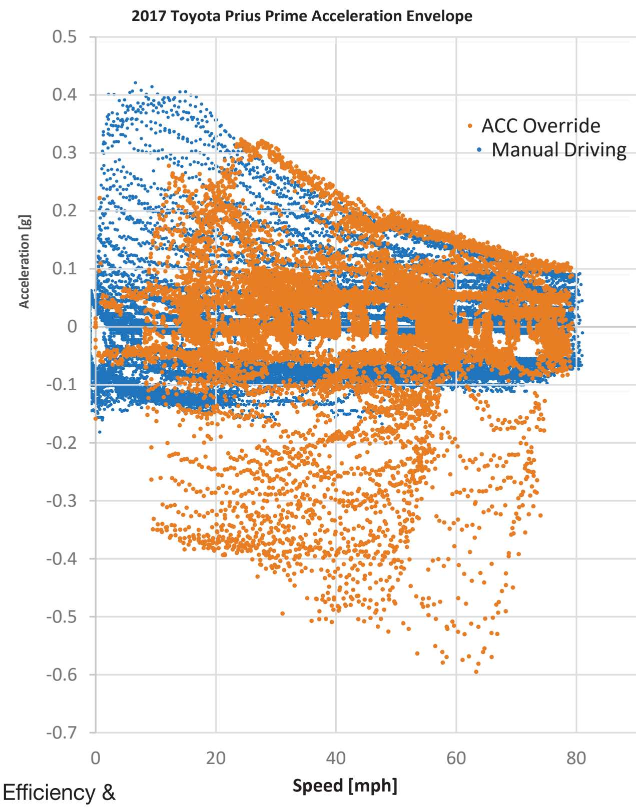
GENERIC ARCHITECTURE

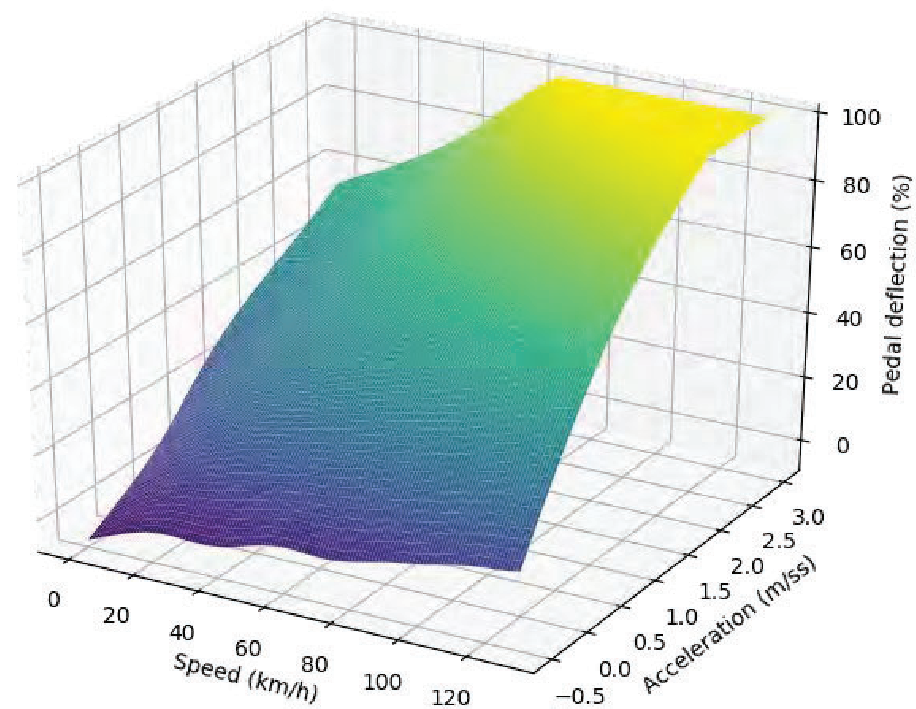


LOW LEVEL SPEED TRACKING

Actuators are mapped on a surface: Acceleration vs. Speed vs. Pedal deflection

Prius





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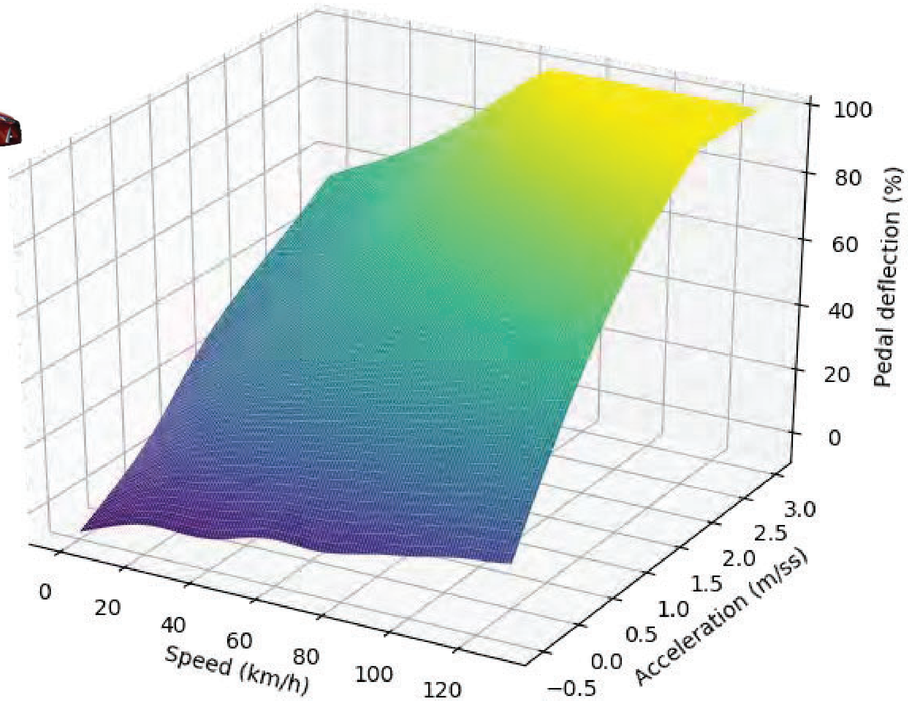

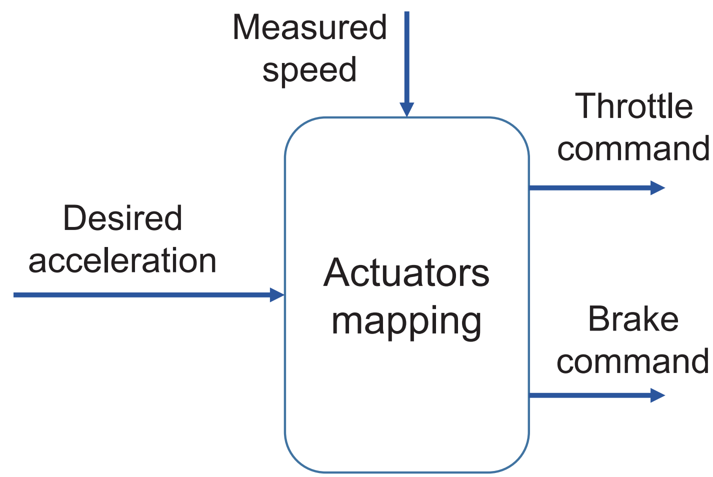

LOW LEVEL SPEED TRACKING

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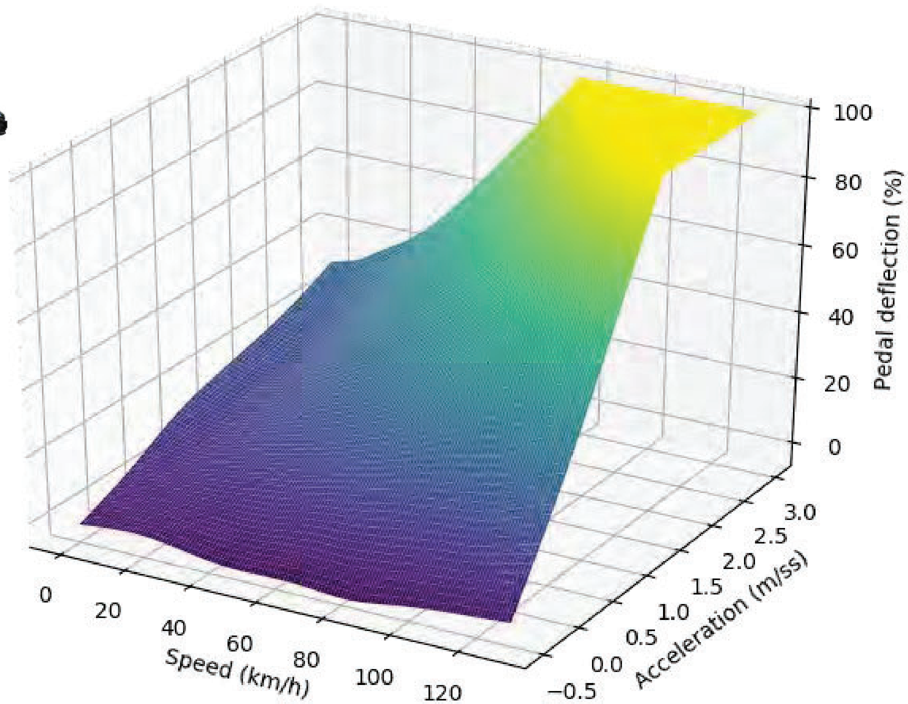
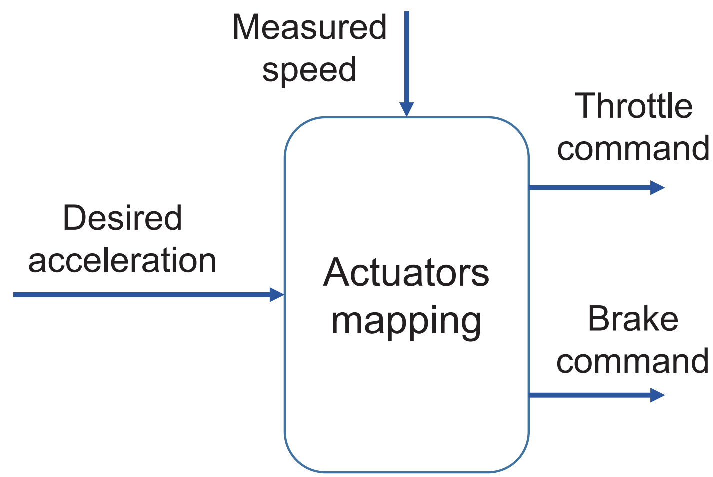
Accord





LOW LEVEL SPEED TRACKING

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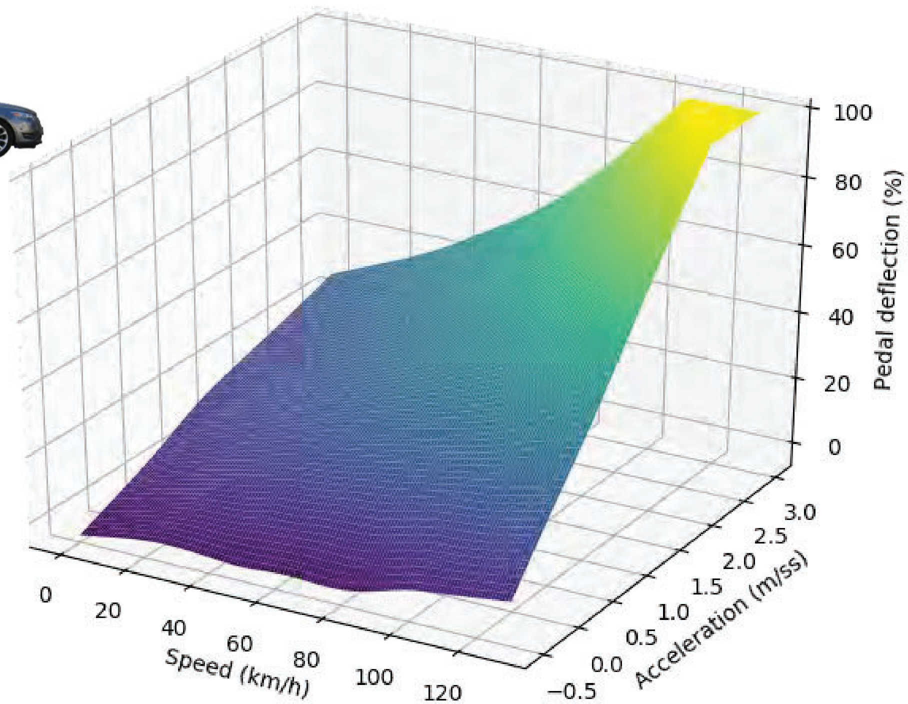
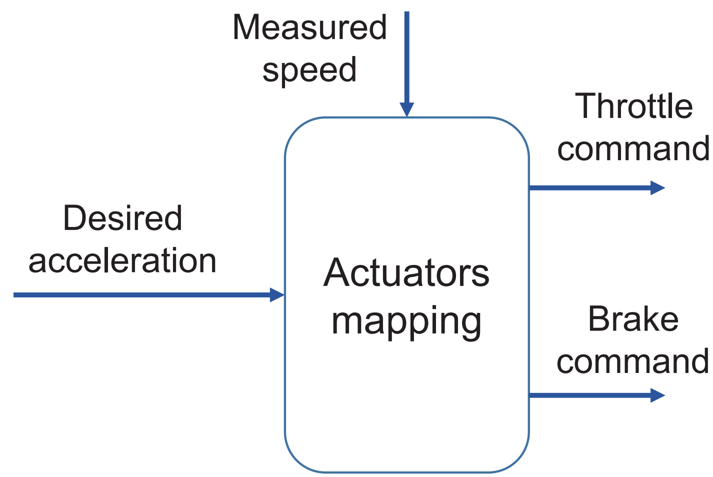
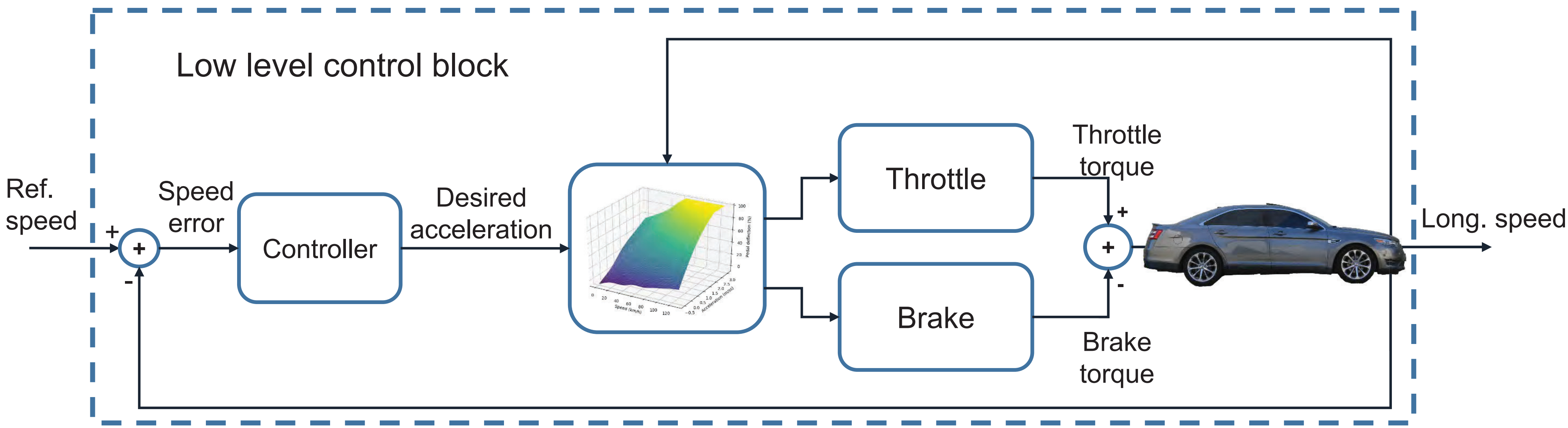
Taurus





LOW LEVEL SPEED TRACKING

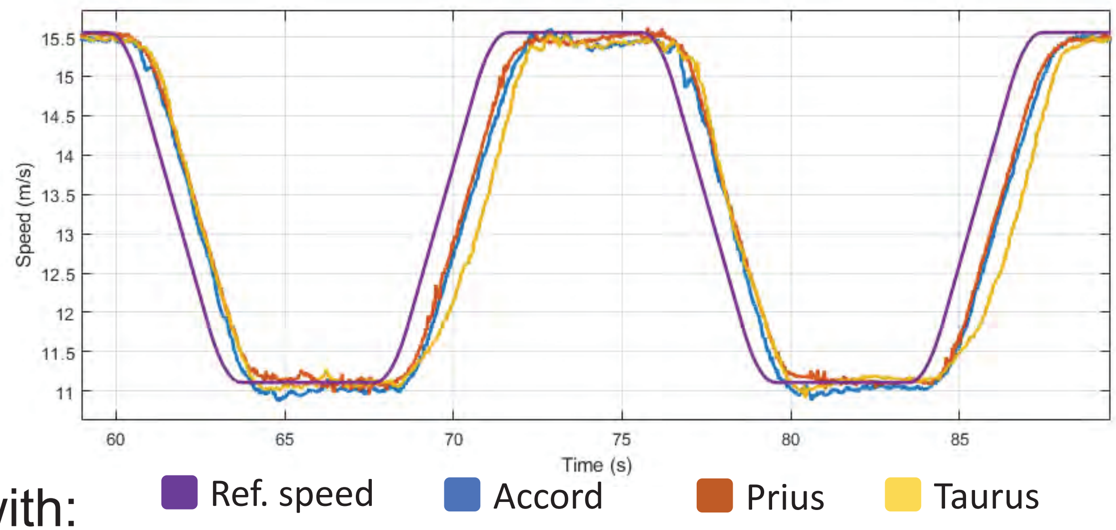
Reference speed tracking structure based on actuators mapping



LOW LEVEL SPEED TRACKING

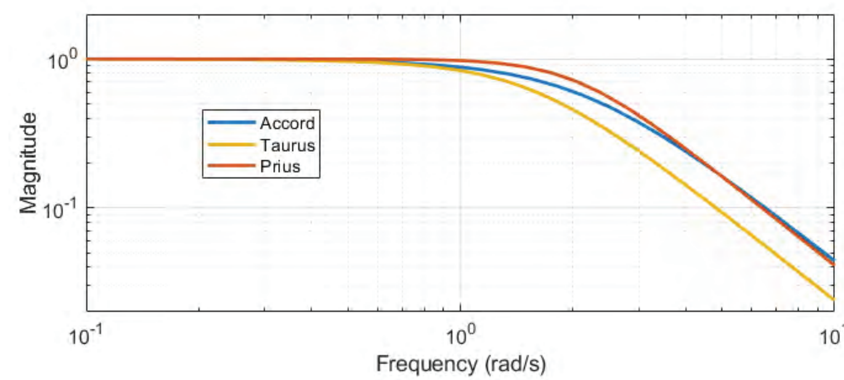
Controller design requirements:

- Fastest response bandwidth
- Damped / no overshoot
- Stable and robust speed tracking



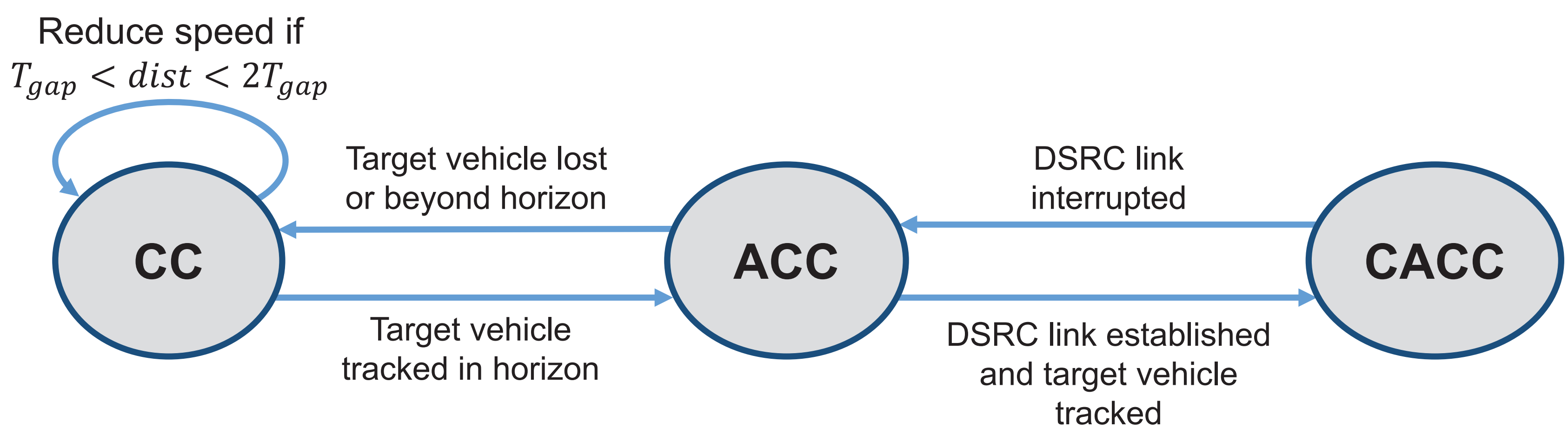
Low level response parameterized with:

- Response bandwidth
- Damping factor
- Acceleration boundaries



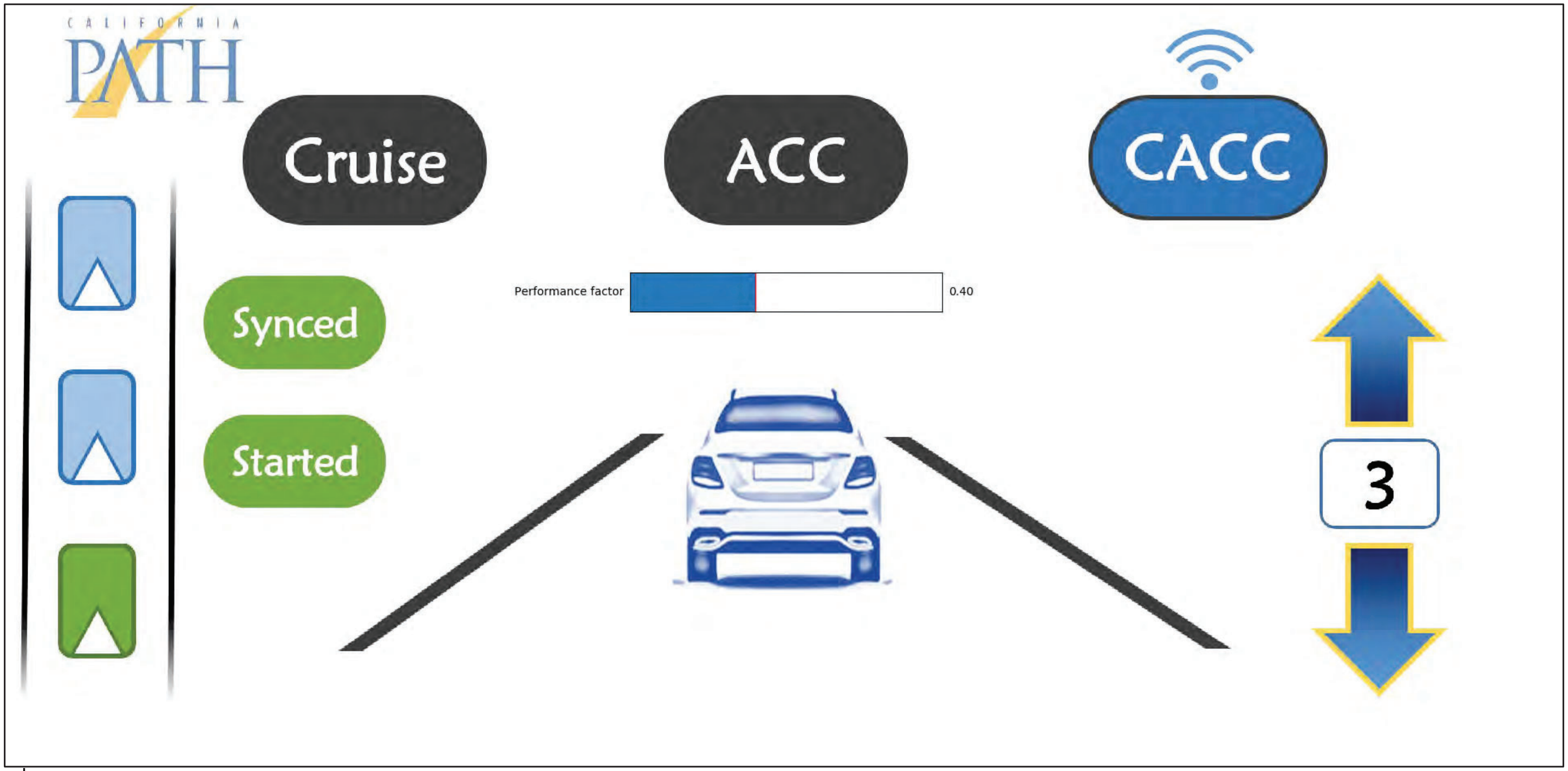
HIGH LEVEL GAP REGULATION

- State machine for highway or test track driving
- Closed-loop transitions remaining on acceleration and jerk boundaries
- Awareness of comfort-performance tradeoff



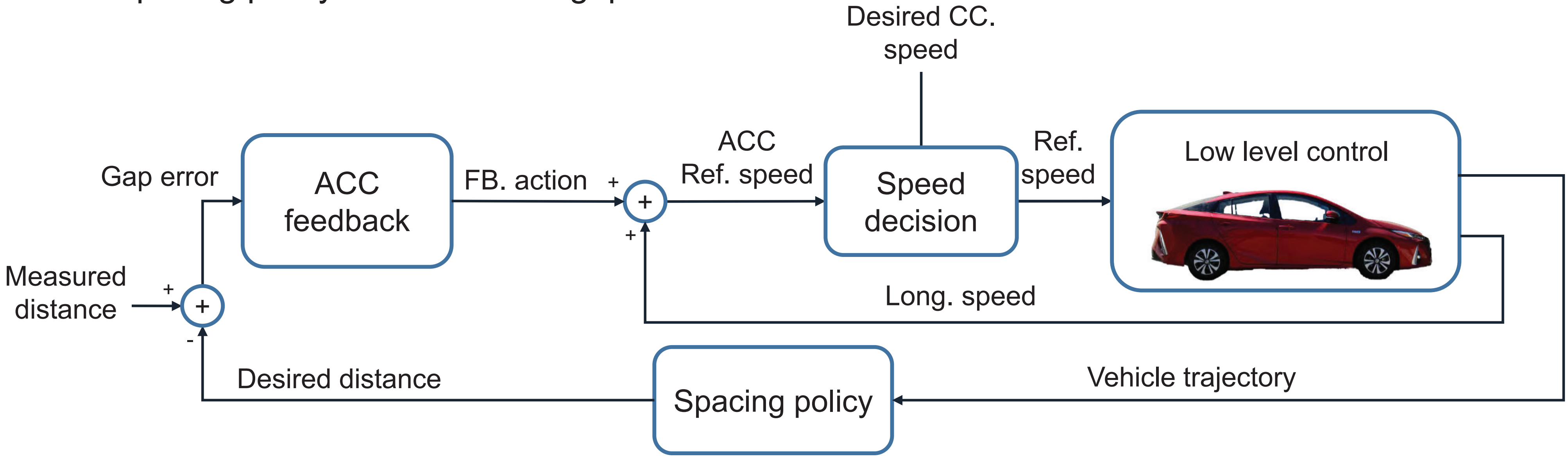
HIGH LEVEL GAP REGULATION

Human Machine Interface for system status and control interaction



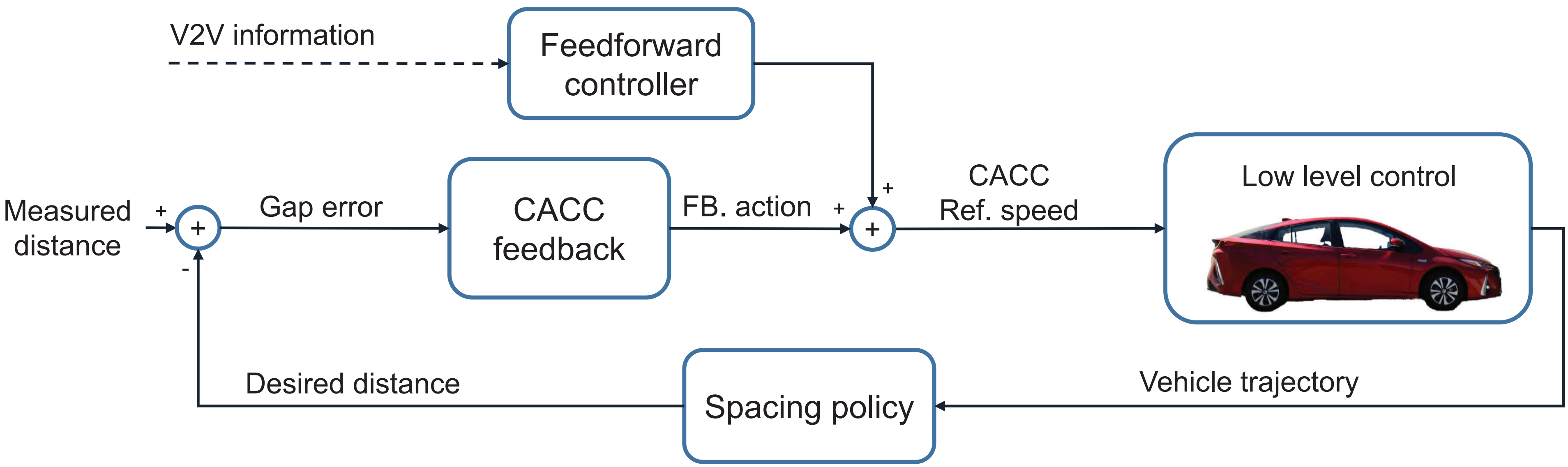
HIGH LEVEL GAP REGULATION

- **Leader** vehicle ACC structure
- Spacing policy based on time gap



HIGH LEVEL GAP REGULATION

CACC control structure



Highway CACC → Constant time gap + standstill distance

Performance CACC → Variable time gap [Flores et al., 2017]

CONTROL DESIGN

Feedback controller

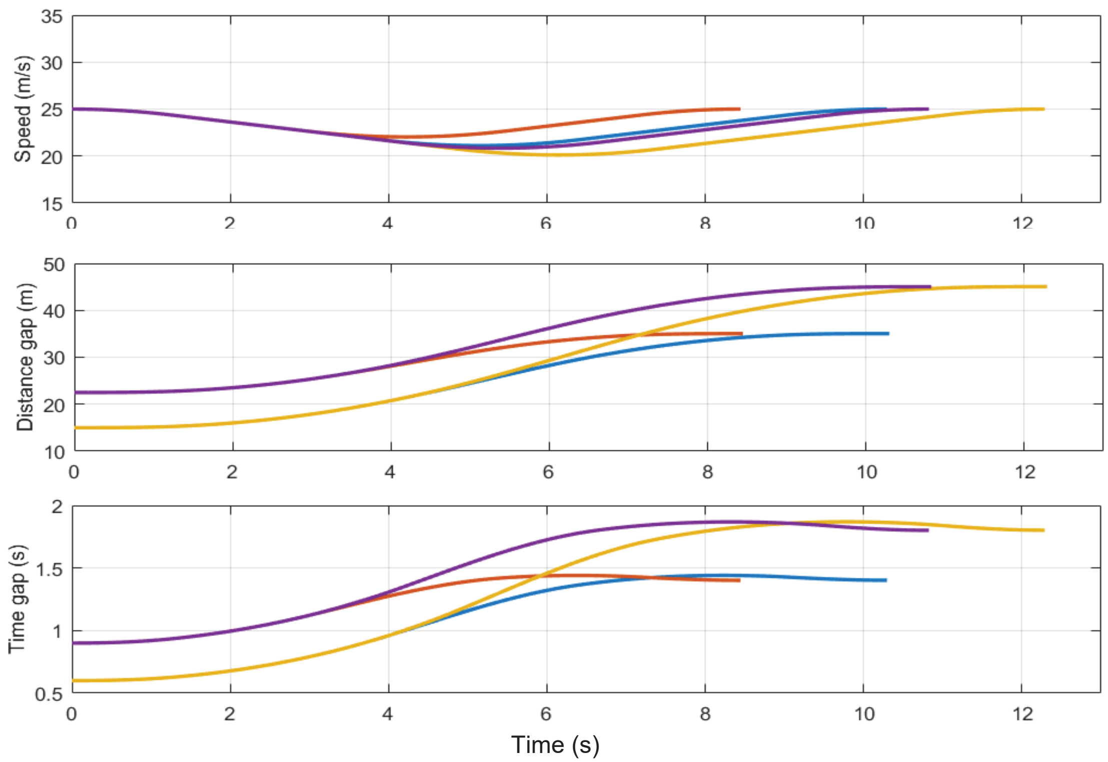
- Corrects following gap error
- Rejects disturbances and model uncertainties
- Is designed as an LPV structure:
  - Target time gap
  - Desired performance vs. comfort tradeoff
- Stabilizes loop and improves string stability

Feedforward controller

- Improves tracking performance significantly
- Filters V2V signals received
- Varies with topology—e.g. preceding-only, leader-predecessor.
- Uses subject and preceding vehicle dynamics model

CONTROL DESIGN

- Dynamics-constrained time gap management system



$V_{eq} = 25\ m/s$

$V_{min} = 12\ m/s$

$A_{max} = -1\ m/s^2$

$J_{max} = -0.8\ m/s^3$

- (purple) $h = 0.9s \rightarrow 1.8s$
- (yellow) $h = 0.6s \rightarrow 1.8s$
- (orange) $h = 0.9s \rightarrow 1.4s$
- (blue) $h = 0.6s \rightarrow 1.4s$

CONTROL DESIGN

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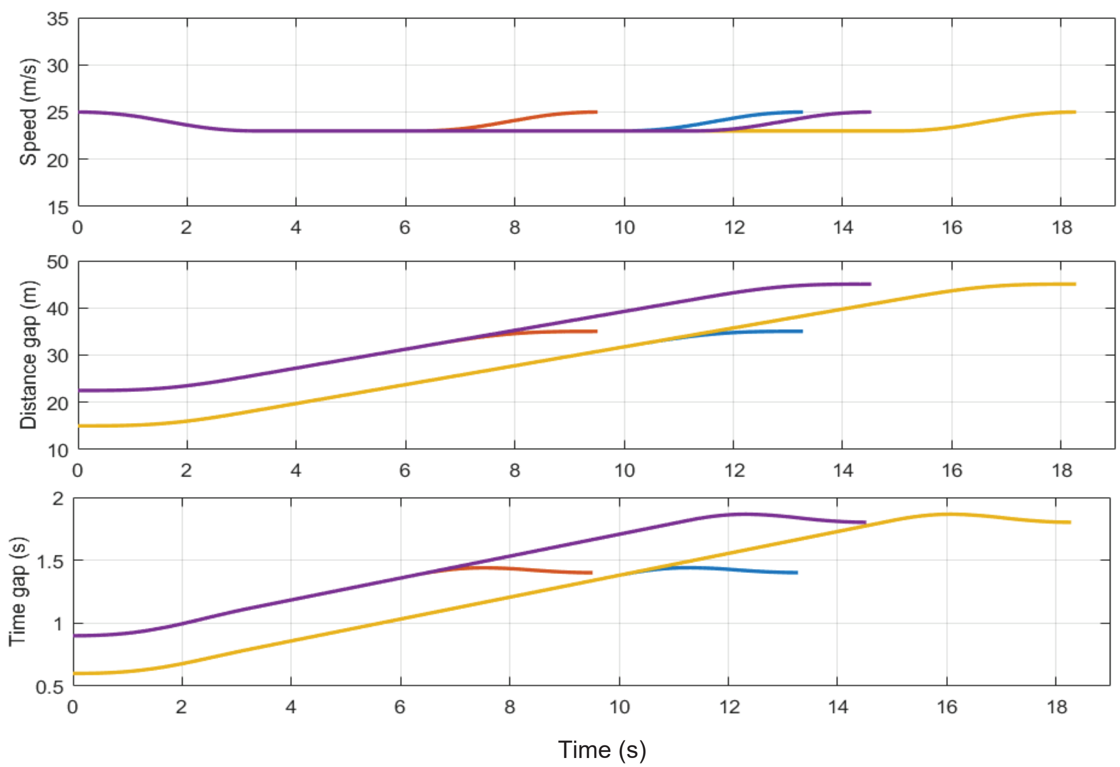


$V_{eq} = 25\ m/s$

$V_{min} = 23\ m/s$

$A_{max} = -1\ m/s^2$

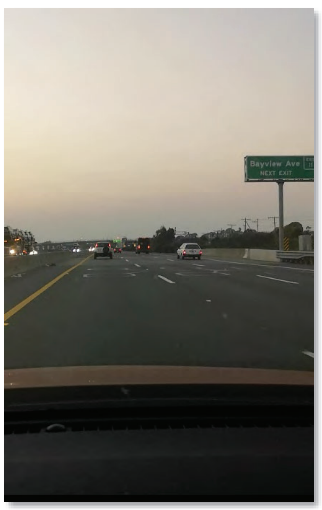
$J_{max} = -0.8\ m/s^3$

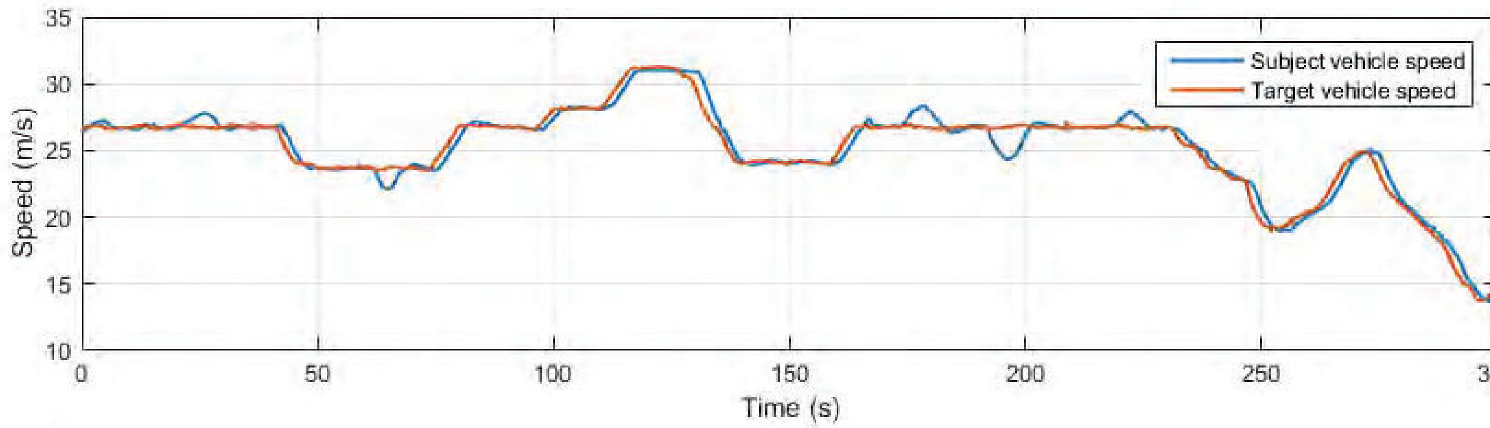
- $h = 0.9s \rightarrow 1.8s$ (purple)
- $h = 0.6s \rightarrow 1.8s$ (yellow)
- $h = 0.9s \rightarrow 1.4s$ (orange)
- $h = 0.6s \rightarrow 1.4s$ (blue)

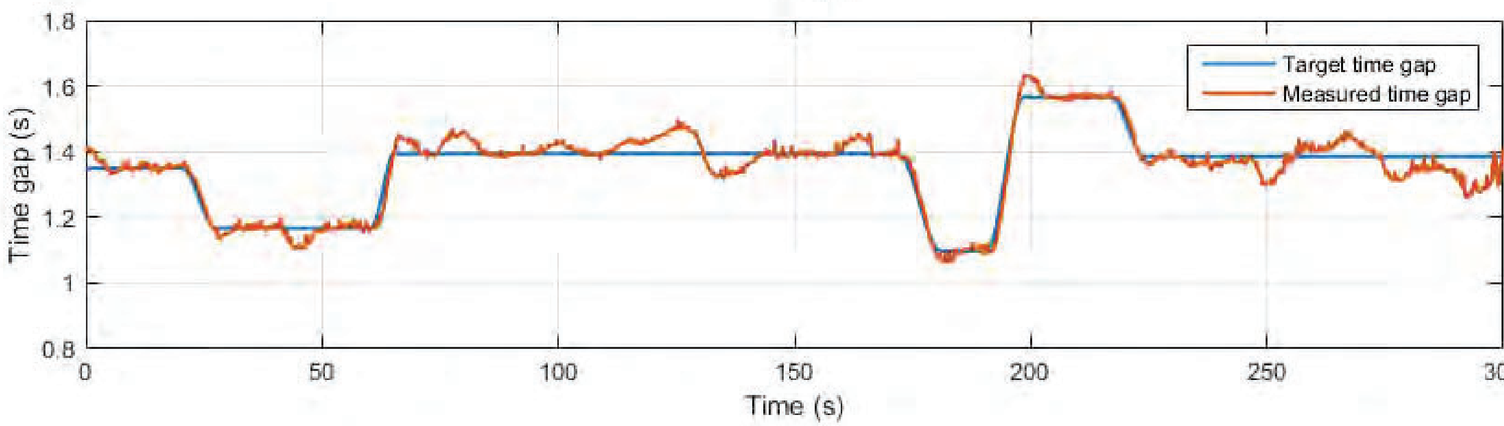
LEADER CAV HIGHWAY TESTS

ACC car-following

Varying target time gap







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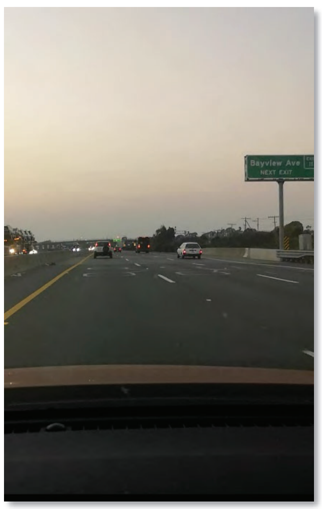
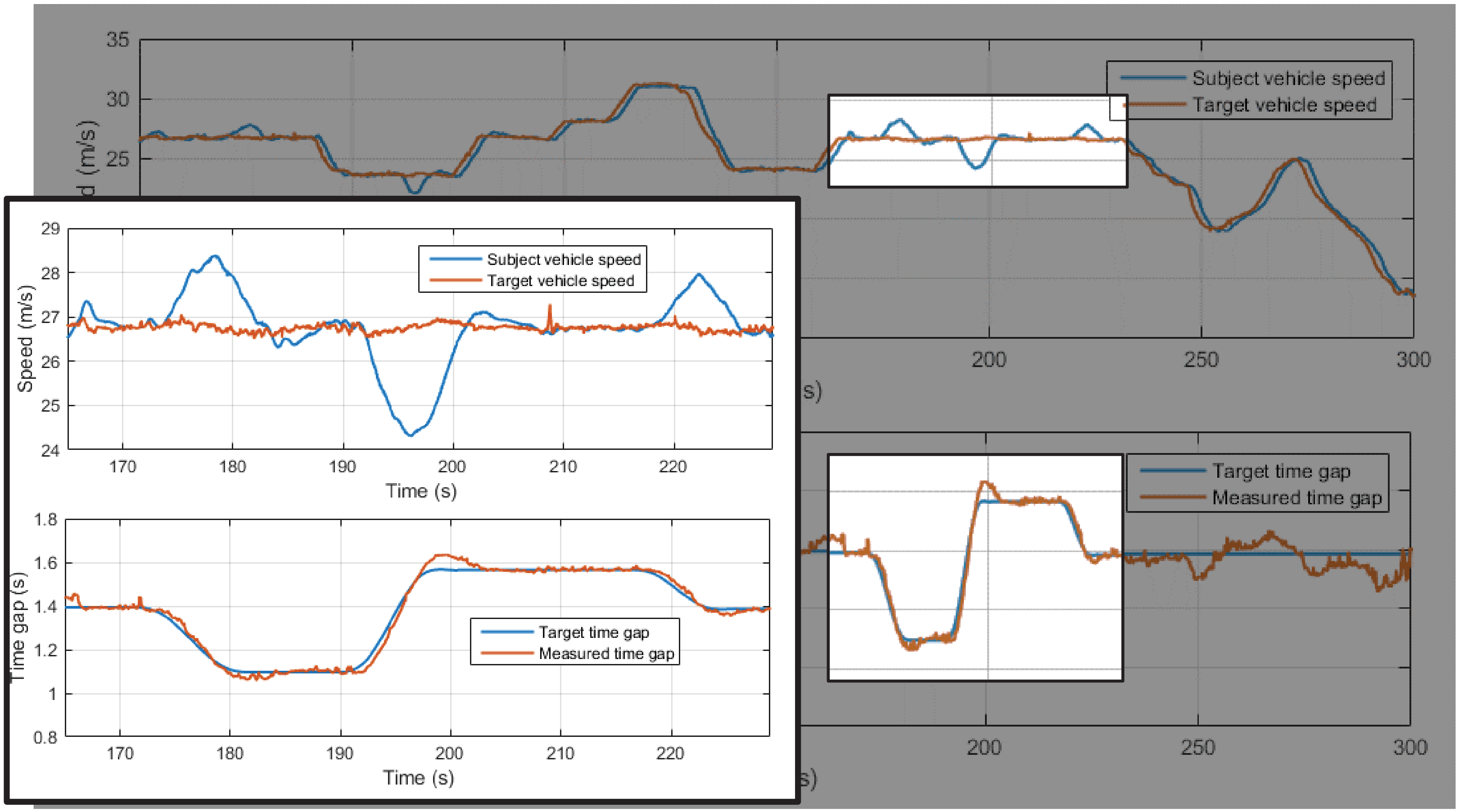


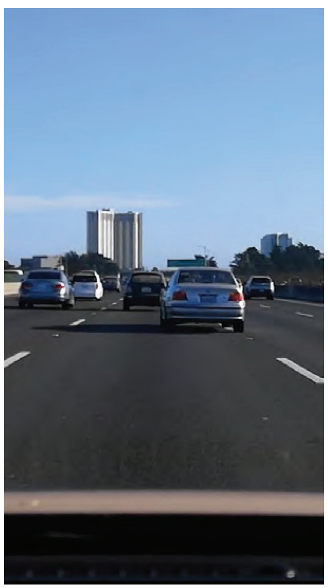


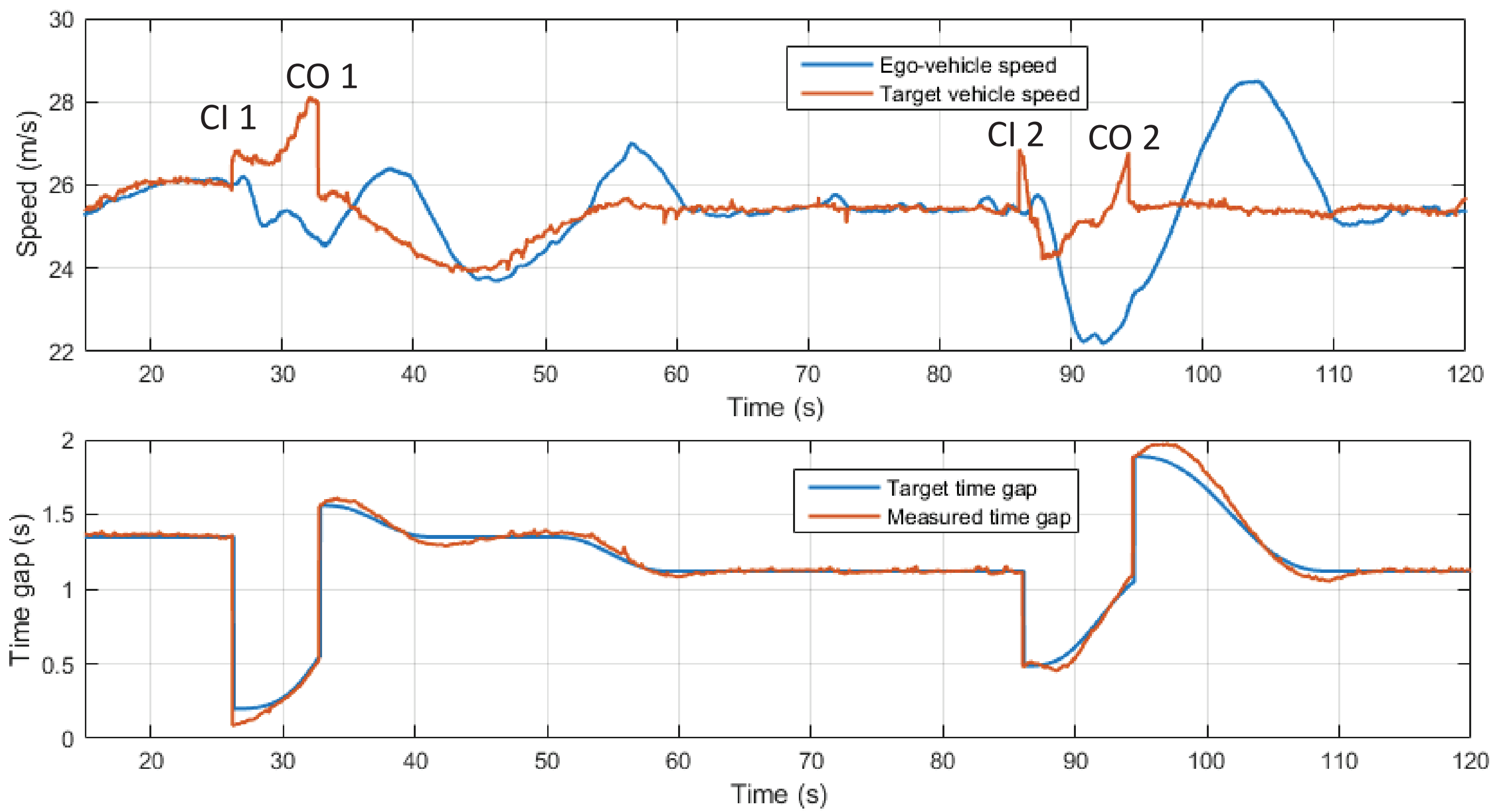
LEADER CAV HIGHWAY TESTS

ACC car-following

Testing the system

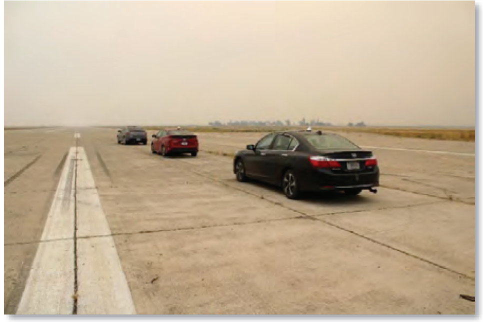
cut-in handling





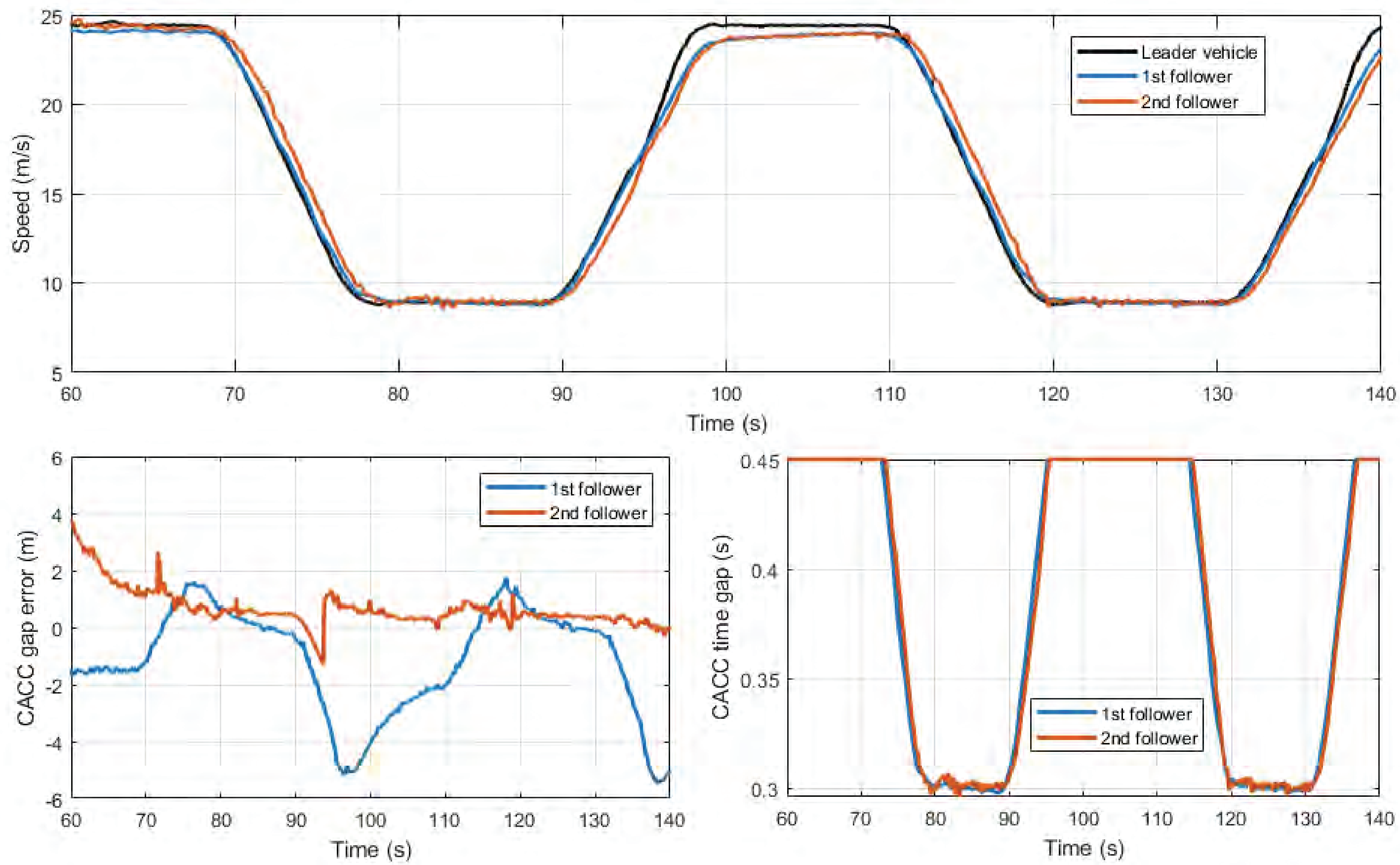
CACC FOLLOWERS TESTS

- CACC system tested in Crows Landing tracks
- Scenarios tested:
  - Speed steps with different rates
  - Smooth speed steps
  - Multisine profile for string stability study
  - Cutting in vehicle
  - Emergency braking



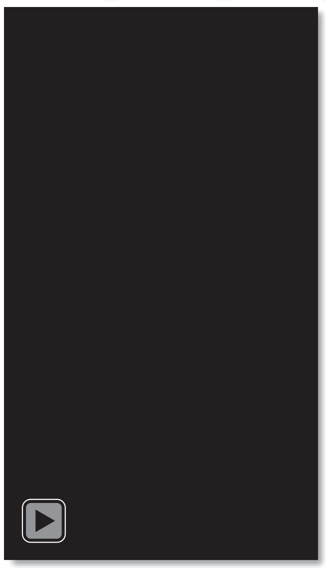
CACC FOLLOWERS TESTS

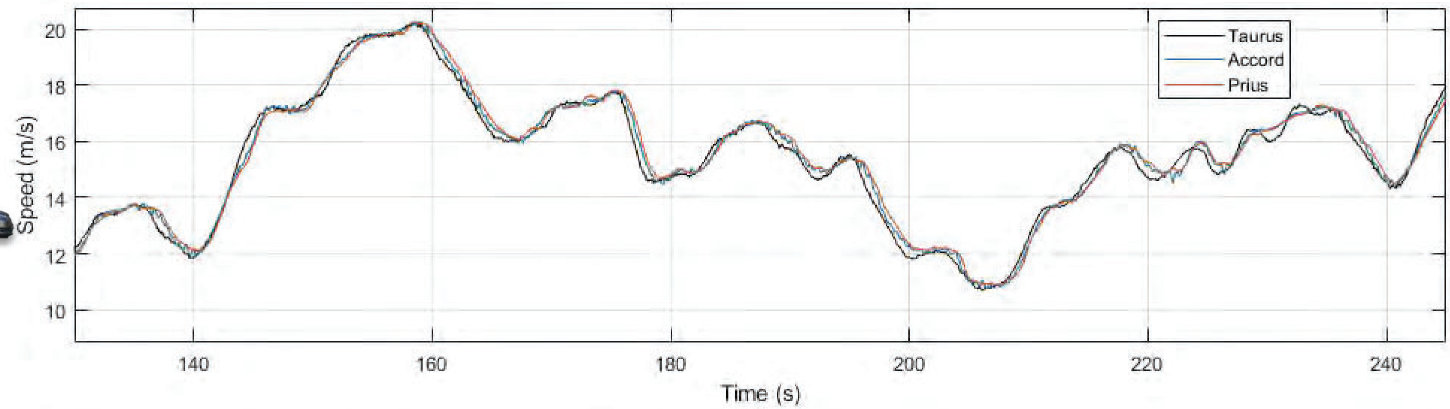
Speed steps of
a=±2.0 m/s²

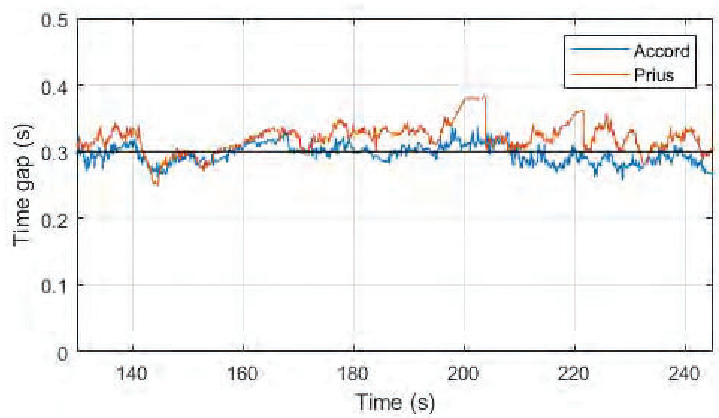


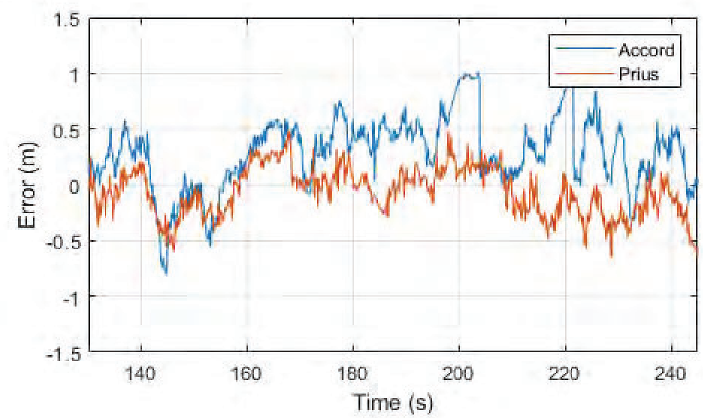
CACC FOLLOWERS TESTS

Multisine acceleration profile







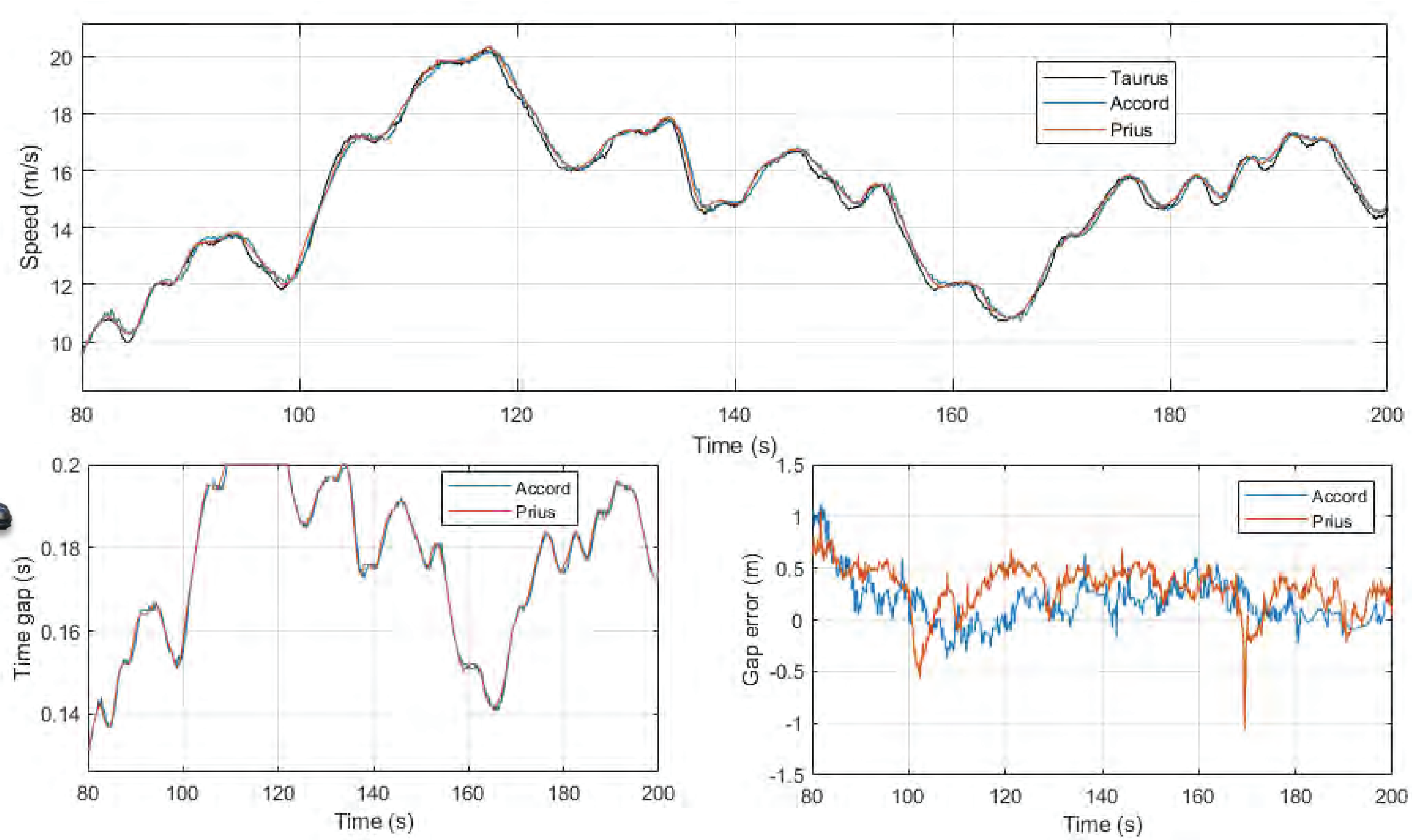


CACC FOLLOWERS TESTS

Multisine acceleration profile

Variable time gap

$$h = 0.05s \rightarrow 0.2s$$



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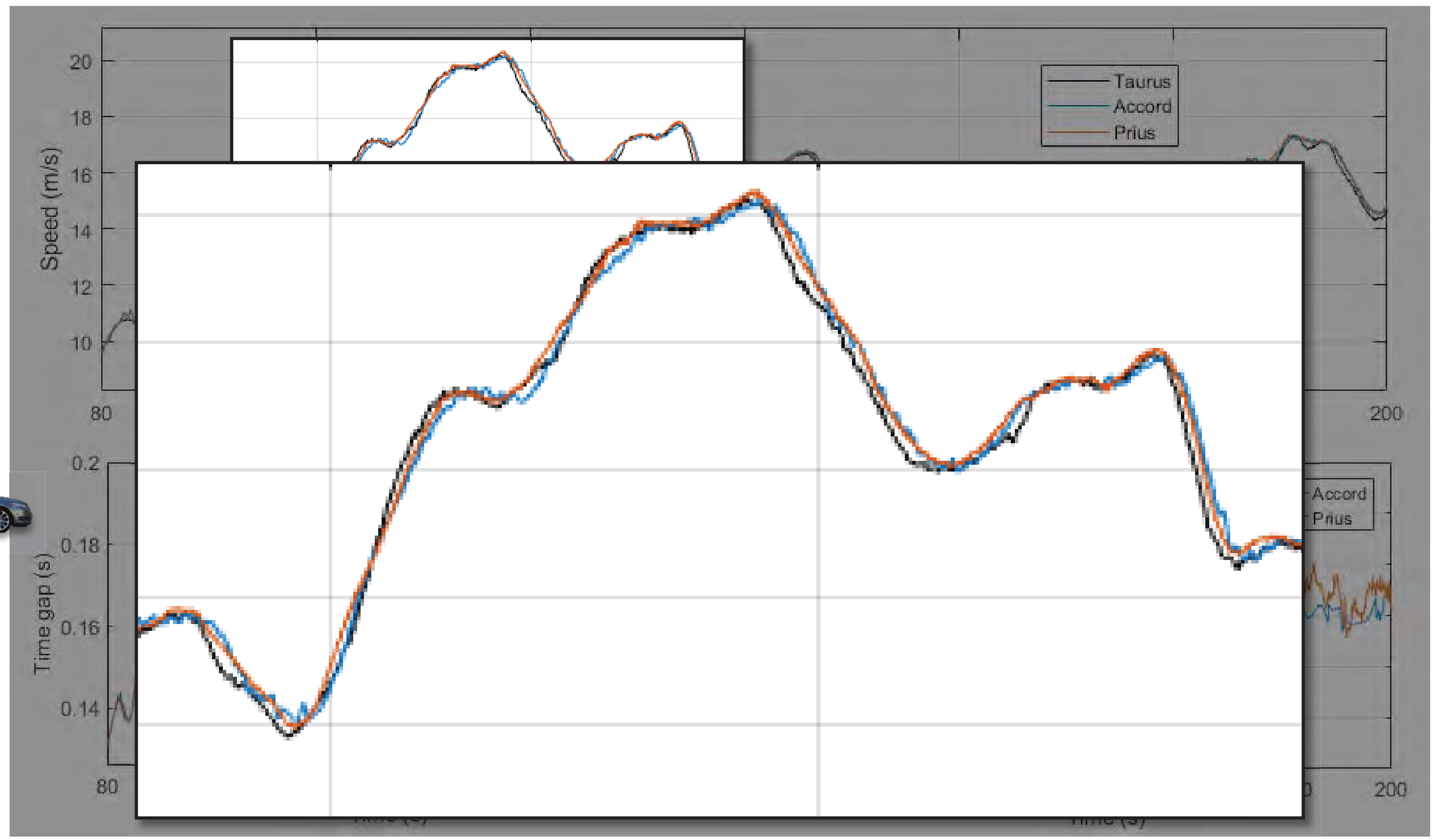
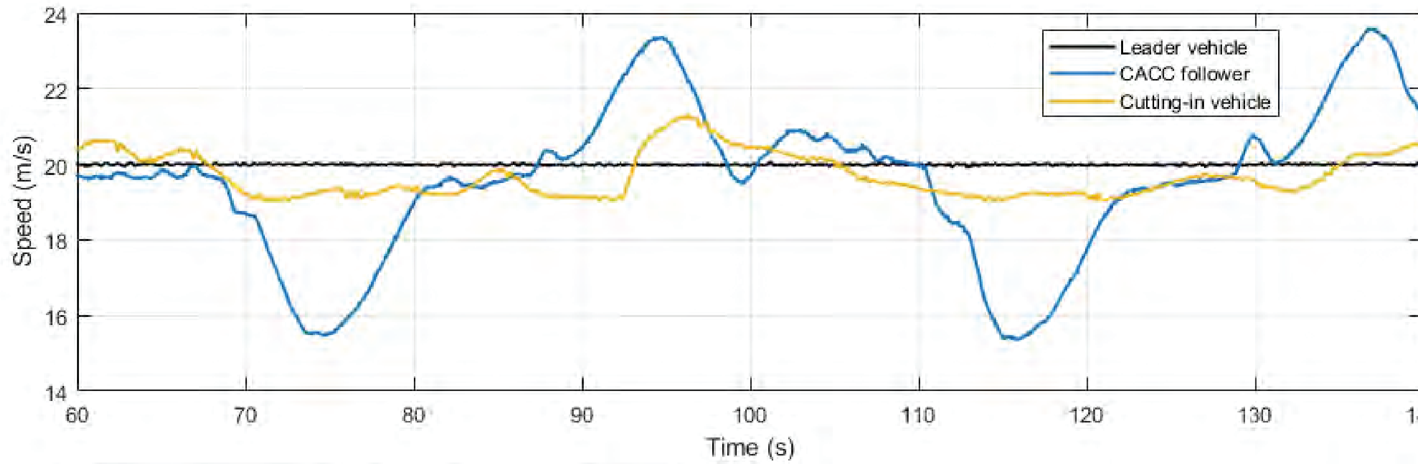
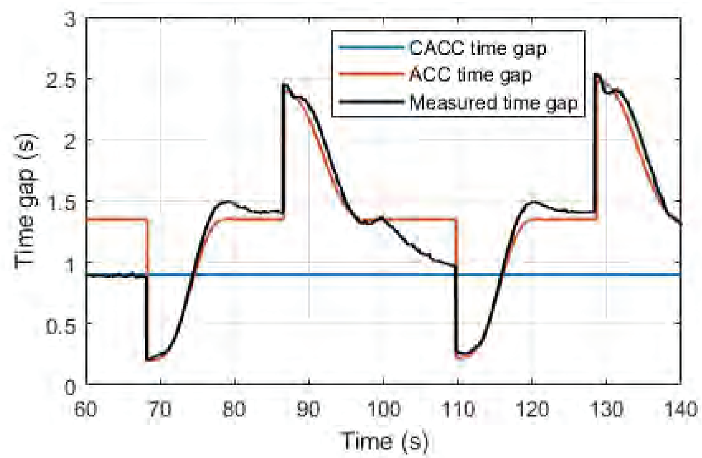


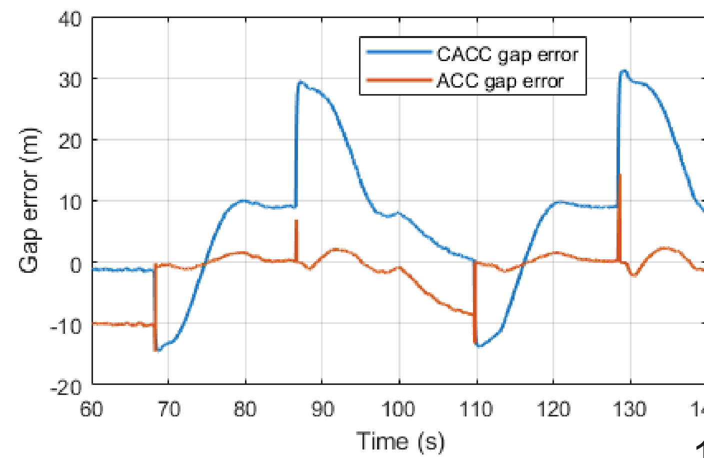
CACC FOLLOWERS TESTS

Cutting-in vehicle within a CACC string

$$h_{ACC} = 1.35s$$
$$h_{CACC} = 0.9s$$







CACC FOLLOWERS TESTS

Cutting-in vehicle within a CACC string

Summary

- Low level speed tracking based on actuators mapping
- Architecture usable both in highway and test tracks (higher performance)
- ACC system handles time gap changes and cut in/out vehicles
- HMI for online supervision and management of the control architecture
- Feedforward/feedback structure for heteregeneous CACC strings
- Developed CACC demonstrated for short time gaps

Conclusions

- CACC of electric, hybrid and ICE vehicles is feasible
- Good performance at short time gaps requires accurate modelling
- Aim short spectral distance between low level responses
- Increase vehicles’ dynamics capabilities upstream
- Cut-in vehicles handled without harming comfort
- Leader-predecessor topology enhances string stability

U.S. DEPARTMENT OF ENERGY

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Thank you.

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