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
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- Design a generic architecture for all types of vehicle dynamics
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- Design a generic architecture for all types of vehicle dynamics
- Yield a system configurable for the expected performance
- Study best string ordering methodology
RESEARCH SCOPE / OBJECTIVES

- Extend CACC capabilities and its positive impact
- 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 control layer

Actuators command

Proprioceptive sensors

Target perception

Vehicle state

Reference trajectory

HMI

V2V network
LOW LEVEL SPEED TRACKING

Actuators are mapped on a surface: Acceleration vs. Speed vs. Pedal deflection
LOW LEVEL SPEED TRACKING

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

Prius

Measured speed → Throttle command
Desired acceleration → Braking command
Actuators mapping

- Speed (km/h)
- Acceleration (m/s²)
- Pedal deflection (%)

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LOW LEVEL SPEED TRACKING

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

Accord

Measured speed
Throttle command
Desired acceleration
Brake command
Actuators mapping

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LOW LEVEL SPEED TRACKING

Actuators are mapped on a surface: Acceleration vs. Speed vs. Pedal deflection
LOW LEVEL SPEED TRACKING

Reference speed tracking structure based on actuators mapping

Low level control block

Controller

Desired acceleration

Throttle

Brake

Throttle torque

Brake torque

Ref. speed

Speed error

Long. speed
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

\[ T_{gap} < dist < 2T_{gap} \]

Reduce speed if

Target vehicle lost or beyond horizon

Target vehicle tracked in horizon

DSRC link interrupted

DSRC link established and target vehicle tracked
HIGH LEVEL GAP REGULATION

Human Machine Interface for system status and control interaction
• Leader vehicle ACC structure

• Spacing policy based on time gap
HIGH LEVEL GAP REGULATION

CACC control structure

V2V information

.Feedforward controller

Gap error

CACC feedback

Desired distance

CACC Ref. speed

Vehicle trajectory

Low level control

Measured distance

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

\[ V_{eq} = 25 \text{ m/s} \]
\[ V_{min} = 12 \text{ m/s} \]
\[ A_{max} = -1 \text{ m/s}^2 \]
\[ J_{max} = -0.8 \text{ m/s}^3 \]

- $h = 0.9s \rightarrow 1.8s$
- $h = 0.6s \rightarrow 1.8s$
- $h = 0.9s \rightarrow 1.4s$
- $h = 0.6s \rightarrow 1.4s$
CONTROL DESIGN

• Dynamics-constrained time gap management system

\[ V_{eq} = 25 \, \text{m/s} \]
\[ V_{min} = 23 \, \text{m/s} \]
\[ A_{max} = -1 \, \text{m/s}^2 \]
\[ J_{max} = -0.8 \, \text{m/s}^3 \]

- \( h = 0.9s \to 1.8s \)
- \( h = 0.6s \to 1.8s \)
- \( h = 0.9s \to 1.4s \)
- \( h = 0.6s \to 1.4s \)
LEADER CAV HIGHWAY TESTS

ACC car-following
Varying target time gap
LEADER CAV HIGHWAY TESTS

ACC car-following
Varying target time gap
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 $a=\pm 2.0 \text{ m/s}^2$
CACC FOLLOWERS TESTS

Multisine acceleration profile
CACC FOLLOWERS TESTS

Multisine acceleration profile

Variable time gap
h = 0.05s → 0.2s
CACC FOLLOWERS TESTS

Multisine acceleration profile

Variable time gap
\[ h = 0.05s \rightarrow 0.2s \]
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 heterogeneous 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
Thank you.