Cooperative Adaptive Cruise Control: Assessing Challenges and Solutions

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B. Brian Park, Ph.D.

Link Lab & Engineering Systems Environment
University of Virginia

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Why CACC?

• Cooperative Adaptive Cruise Control (i.e., automated vehicle platooning – cars move like “train”
• Mobility improvement
  o CACC with 0.6 sec headways
  o Human driven vehicles with 1.8 sec headways
• Fuel savings
  o ~ 20% for following trucks
What are Major Challenges?

- Simulation platform for CACC algorithm development and evaluation
  - Proper vehicle dynamics model
  - Sensor errors & Communications
- Mixed traffic interacting with human driven vehicles
  - Not likely to have 100% Connected-and-Automated vehicles in a near future
- Robust control
- Cyber security
CACC Demonstration

These are all Cadillac vehicles!
Why Vehicle Dynamics?

Same Vehicles

Different Vehicles

CACC Platoon with Four Connected-and-Automated Vehicles
Integrated Framework for CACC Simulation

- **VISSIM** for drivers and traffic control devices
- **PreScan** to explicitly consider vehicle dynamics, sensors & communications
- **MADYMO** for crash severity estimation
- **Driving Simulator** for a human driver interacting with CACC
CACC Evaluation under Cyber-Attack

• Set a constant target speed of 24 m/s
  \[ v_T(t) = 24 \, m/s, \quad \forall \, t \in [0, T] \]
• Platoon accelerated to target speed for 15 seconds and then became stabilized
• To mimic a cyber-attack in radar or DSRC, false data were given to 3\textsuperscript{rd} vehicle around 20 seconds
Case Study: CACC Cyber Attack
Crash Severity Evaluation

![Pulse Function Graph]

![Frontal - Driver Stars]

<table>
<thead>
<tr>
<th>Body region</th>
<th>Injury probability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Head Assessment</td>
<td>0.0035</td>
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<tr>
<td>Neck Assessment</td>
<td>0.0534</td>
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<tr>
<td>Chest Assessment</td>
<td>0.0493</td>
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<tr>
<td>Femur Assessment</td>
<td>0.0151</td>
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<tr>
<td>Frontal - injury probability</td>
<td>0.116</td>
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</table>
CACC under Mixed Traffic

• CACC with 100% connected-and-automated vehicles is not likely (except for dedicated lanes) in a near future

• When CACC vehicles run into a human driven vehicle, they fall back to Adaptive Cruise Control (ACC)
  o String stability issue
  o Major issue with multiple ACC vehicles
ACC vs CACC vs quasi-CACC

ACC

0

Radar beams

1

Unconnected vehicle

CACC

0

Communication

1

Quasi-CACC

0

Unconnected vehicle

1

Quasi-CACC

0

Connected human-driven vehicle

1
CACCu (CACC w/ unconnected vehicle)

- CACC capable (i.e., CAV) vehicle runs into unconnected human driven vehicle but vehicle #2 is connected and possibly automated.
- Goal – design control policy of ego-vehicle to outperform ACC based on the information from vehicle #2 and radar measurement of vehicle #1.
ACC vs CACC\textsubscript{u}

Ego vehicle overshoots the speed - string unstable

Ego vehicle no overshooting - string stable

1st and 2nd preceding vehicles' trajectories are from NGSIM data
**ACC vs CACCu**

<table>
<thead>
<tr>
<th>Entering time</th>
<th>Control type</th>
<th># of speed overshootings</th>
<th>Acceleration peak (m/s²)</th>
<th>Acceleration RMS (m/s²)</th>
<th>Spacing error peak (m)</th>
<th>Spacing error RMS (m)</th>
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<tbody>
<tr>
<td>0 min</td>
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<td>0.43</td>
<td>1.58</td>
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<td>1.60</td>
<td>0.51</td>
<td>4.18</td>
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<tr>
<td>20 min</td>
<td>CACCu</td>
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<td>1.62</td>
<td>0.35</td>
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<td>0.91</td>
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<tr>
<td></td>
<td>ACC</td>
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<td>1.48</td>
<td>0.36</td>
<td>4.50</td>
<td>1.90</td>
</tr>
</tbody>
</table>

In average, CACCu show 100% less speed over shootings, 10.4% less acceleration RMS, and 41.7% less spacing errors.
hCACC (CACC for human driven vehicle)

- A human driven vehicle (connected but no sensors) follows a connected or connected-and-automated vehicle
- Goal – help human driver achieve string-stability on speed and acceleration, that is, human driver determines comfortable spacing
ACC vs hCACC – Speed Profile
ACC vs hCACC – Acceleration Profile

![Graph 1](image1.png)

![Graph 2](image2.png)
ACC, CACC, CACC\textsubscript{u} and hCACC

ACC: string stable at headway > 2.5s

CACC: string stable at headway of 0.6s

CACC\textsubscript{u}: 0.9~1.4s

hCACC: string stable at human-chosen headway
Contact Information

B. Brian Park, Ph.D.
University of Virginia
bp6v@virginia.edu