An Integrated Safety Assessment Tool for Connected and Automated Vehicles Under Cyber-Attack

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ABSTRACT

Connected and automated vehicles (CAV), due to more accurate controls and almost ignorable reaction time, are expected to have significant contribution in transportation, economy, environment, and safety. However, researchers pointed out that it is necessary to investigate the cybersecurity implications of CAVs due to the special needs and vulnerabilities toward potential cyber-attacks. To quantitatively evaluate the safety impact of extreme events, this research developed a simulation platform that can simulate CAV systems and estimate the crash severities. In the simulation platform, we integrated the vehicle dynamics model (VDM), radar sensor, Dedicated Short Range Communication (DSRC) devices, and control module to simulate CAVs more realistically. For this purpose, we adopted the simulation software PreScan and MADYMO for VDM and injury assessment, respectively. A Cooperative Adaptive Cruise Control (CACC) on a straight highway was simulated with four TOYOTA Yaris vehicles, where CACC controls the vehicles based on the leading vehicle and the preceding vehicle information. A cyber-attack scenario was generated for the third vehicle within a four-vehicle platoon. A cyber-attack case of data jam in DSRC communication was simulated only for the attacked vehicle. A rear-end crash occurred and the following vehicles had fluctuations in their speed profiles. This platform is expected to be used in the development and evaluation of new CACC algorithms, their impacts of various sensor errors or cyber attacks.

Methodology

The proposed simulation platform consists of the following:

- **VDM** was simulated to reflect vehicle dynamics behavior (Jazar 2009)
- **Sensor** error and **communication** delay are considered
- Radars measure distance and relative speed of objects
- GPS provides location of leading vehicle via Basic Safety Message in DSRC (McGurrin 2012)
- **CACC control** aims to let vehicles maintain desired gap (Milanes et al. 2014)
  - For upper-level control, Proportional-Integral (PI) controller calculates desired speed with detected data
  - For lower-level control, Proportional-Integral-Derivative (PID) controller determines the control variable, i.e. throttle or brake level, as input to VDM
- When a **crash** occurs during the simulation, the crash is **reconstructed** and pulse function is generated
- Based on crash function, human dummy model, and vehicle setting, **injury probability** is estimated

Simulation Results

CACC cruising validation in simulation:

- Target speed $v_T(t) = \begin{cases} 30\text{m/s}, & v_T \in [0, T/2] \\ 20\text{m/s}, & v_T \in (T/2, T] \end{cases}$
- Platoon needed around 30 seconds to be stabilized from 0 to 30m/s, and around 20 seconds from 30m/s to 20m/s

Data jam in DSRC was simulated for the 3rd vehicle, where the location and speed values were frozen:

- Rear-end crash happened when attacked vehicle had rapid deceleration and its following vehicle could not avoid collision
- For the crashed vehicles, pulse function was generated for injury assessment
- Estimated injury probabilities of passengers were 7.2% in the preceding vehicle and 25.0% in the following vehicle

Conclusions

- The simulation results showed that the platform simulates CACC platoon realistically
- A cyber-attack of DSRC communication jam resulted in a crash when the attacked (3rd) vehicle had rapid maximum deceleration, and its following vehicle could not avoid collision to the 3rd vehicle
- Estimated injury probabilities were not very big but possible severe injury (25%) was expected
- Therefore, it is necessary to ensure CACC control algorithms are capable of:
  - Resisting the sensor and communication attacks and detecting the errors
  - Providing collision free condition even though the preceding vehicle behaves abnormally
- Future research:
  - To analyze the vulnerable parts of CACC system based on the simulation results and strengthen its control mechanism to minimize crash severity
  - To assess the impact of extreme cases in CAV systems to mixed traffic with human-driven-vehicle (driving simulator) in simulation loop

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