Preceding Vehicle Identification for Cooperative Adaptive Cruise Control Platoon Forming
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Summary
Cooperative Adaptive Cruise Control (CACC) has shown its great potential in enhancing traffic efficiency and sustainability. While past research efforts focused on the development of CACC systems and their demonstrations, few of them considered in detail how to form a CACC platoon in real traffic, where proper identification of preceding vehicle is required. To ensure safe and reliable CACC operations, the following vehicle needs to establish correct connection with its preceding vehicle. Although this can be done by matching information shared by surrounding vehicles with the ego-vehicle’s radar/lidar measurements, the existence of sensor errors makes it as a challenging task. Considering possible sensor errors in real traffic, this paper proposes a procedure of identifying preceding vehicle under connected vehicle environment and evaluates three preceding vehicle identification systems (PVIS), namely, location-based PVIS, distance-based PVIS, and integrated PVIS combining both location and distance information. Mathematical models of PVISs are developed. Performance evaluation of the PVISs are conducted based on real vehicle trajectory data from Next Generation Simulation (NGSIM), which reflects how vehicles’ relative positions change in a high-density segment of highway. The feasibility, performance, and potential of the three PVISs are compared. The results show that location-based PVIS requires a relative positioning accuracy below 1.15m to ensure an acceptable identification time with 0 failure rate. The integrated PVIS has the best performance, providing 99% confidence in identifying preceding vehicle within 1.3 seconds under typical sensor error settings.

Methodology

Identification Procedure
- S: the state of the actual preceding vehicle from radar
- C: the states of surrounding vehicles from communications
- Determine the candidate for preceding vehicle: |C-S| ≤ e?
- € is a dynamic threshold that guarantees a low failure rate
- Repeat the candidate searching when no more than one candidate is found

Preceding Vehicle Identification Systems (PVIS)
- GPS-based PVIS: S and C are relative locations of vehicles
- UWB-based PVIS: S and C are intervehicle distances
- Integrated PVIS: location and distance are both used
- € can be derived from the mathematical model of the PVIS in pursuit of a failure rate of 10⁻⁸

Performance Evaluations
- Real vehicle trajectory data from NGSIM program are used to reconstruct the traffic on high-density highway for 15min
- Relative positioning error of GPS is modeled as the sum of irreducible random noise and multipath effect bias that has limited magnitude and duration; UWB error and radar errors are assumed to follow unbiased normal distribution
- Measures: failure rate, average and 99th percentile time consumption

Evaluation Results

- Two-step PVIS that uses a larger € but required two-step confirmation is found more efficient than one-step PVIS
- No incorrect identification occurred except for two-step GPS-based PVIS with positioning error>1.6m

Conclusions

- To ensure the 99th percentile of identification time < 10s and no incorrect identification, the required GPS relative positioning accuracy was 0.9m for one-step PVIS and 1.15m for two-step PVIS
- These accuracies are realizable only for highway scenarios under moderate multipath effect, when low-cost GPS is used
- UWB-based PVIS outperformed GPS-based PVIS. Even with the ranging error of 0.2m, the 99th percentile of time consumption was below 6s
- Because this ranging accuracy of UWB has been proven achievable in multipath environment, UWB-based PVIS is more suitable for urban scenario
- Under the theoretical failure rate of 10⁻⁸, no incorrect identification was observed in all simulations except for two-steps GPS-based PVIS, which is sensitive to the multipath bias in GPS positioning
- The integrated PVIS of UWB and GPS showed promising performance and the potential to lower the requirement for sensor accuracies

Future Work
- Enhance PVIS for mixed traffic conditions instead of 100% connected vehicle environment
- Consider other automated vehicle driving applications that needs vehicle identification such as cooperative merging

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