Cooperative Ramp Merging with Vehicle-to-Cloud Communications: A Field Experiment

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Introduction

In traditional human driving without ADAS, ramp merging is one of the major causes of traffic congestion and accidents. The ramp vehicles cannot always enter the main line at an appropriate speed or at a safe distance with the merging vehicles, especially when the merging distance is too short, or the driver's vision is blocked. The vehicles on the main line have to adjust their speed and/or change their lanes abruptly to avoid potential collisions with the merging vehicles, which heavily affects the upstream traffic flow. Therefore, we design a cooperative on-ramp merging system for connected vehicles with Vehicle-to-Cloud (V2C) communication.

Background

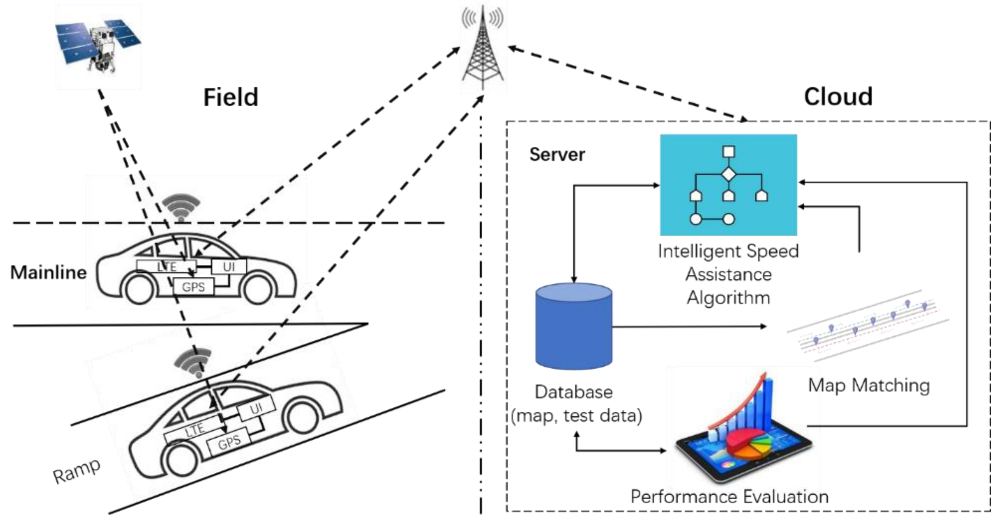
- A feedforward/feedback motion controller is adopted to generate the target acceleration for vehicles to conduct ramp merging. In the road experiment, acceleration suggestion is transformed into speed suggestion and shown by Intelligent Speed Assistance (ISA).

$$\underbrace{a_{ref}(t+\delta t)}_{\text{Advisory acceleration}} = -\alpha_{ij}k_{ij}\cdot\left[\underbrace{\left(r_i(t)-r_j(t-\tau_{ij}(t))+l_j+v_i(t)\cdot\left(t_{ij}^{g}(t)+\tau_{ij}(t)\right)\right)}_{\text{Longitudinal position consensus}}+\gamma_i\cdot\underbrace{\left(v_i(t)-v_j(t-\tau_{ij}(t))\right)}_{\text{Longitudinal speed consensus}}\right]$$

- The advisory speed compensation: A human factor model is integrated into ISA to improve the drivers performance by analyzing the driver behavior and then compensating the speed tracking error. For more information please refer to our previous research "Driver Behavior Modeling Using Game Engine: A Learning-Based Approach".

$$\underbrace{\hat{v}_i(t+\delta t)}_{\text{Compensated advisory speed}} = \underbrace{v_i(t)+a_{ref}(t+\delta t)\cdot\delta t}_{\text{Raw advisory speed}} + \underbrace{\hat{y}(t+\delta t)}_{\text{Predicted error}}$$

System Architecture



Experiment Design

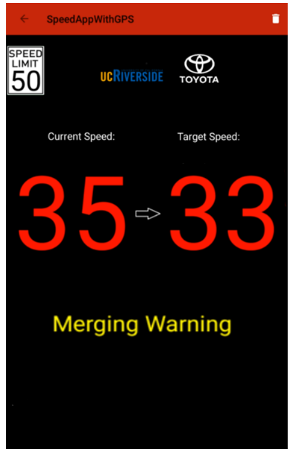
GNSS unit:
U-blox C94-M8P-2
Accuracy:
1.5m (0.4m in still)
Update Rate: 8Hz

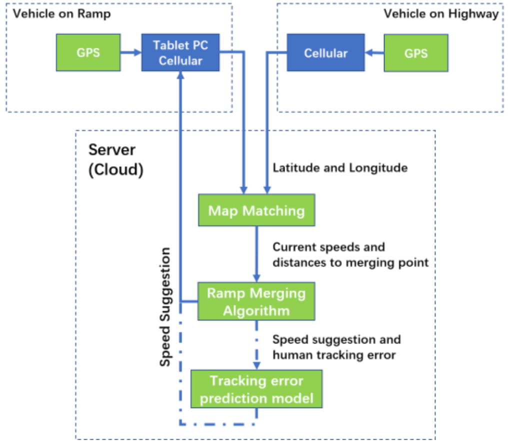
ISA Device

Cellular Hotspot

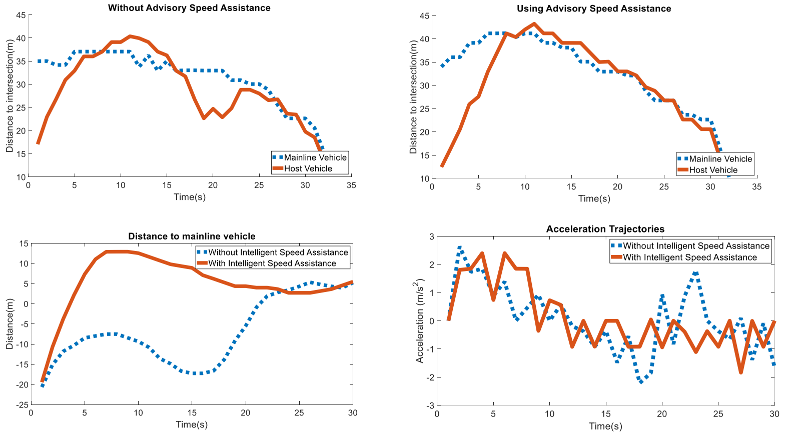
Cloud Server:
Running Windows Server 2012 system, with algorithm programmed in Python. Can be replaced by Amazon Server.

Parameters		Ramp vehicle	Mainline vehicle
GPS antenna to front bumper		2 m	2.2 m
GPS antenna to rear bumper		2.5 m	2.7 m
Initial speed		10 mph (4.5m/s)	38 mph (17 m/s)
Desired speed		-	38 ± 4 mph (17 ±2 m/s)
Desired acceleration range		$\pm 2\ m/s^2$	$\pm 1\ m/s^2$
Speed limit for suggested speed		40 mph (18 m/s)	-
Initial distance to merging point		400 m	430 m
Initial intervehicle distance		30 m	
Initial time gap		6 s	
Desired time gap		0.5 s	
Control gains	Speed	5	
	Distance	1	
Low speed minimum intervehicle gap		2 m	
Time duration of merging		25 to 30 s	
Communication rate		1 Hz	





Experiment Result



- Reduce the effect on upstream traffic.
- Smoother speed trajectory, less jerk, faster speed matching and more stable intervehicle distance maintaining.
- 13% reduction in acceleration variance and 12.5% reduction in mean absolute acceleration.