Deep Learning-based Human-Driven Vehicle Trajectory Prediction and its Application for Platoon Control of Connected and Autonomous Vehicles

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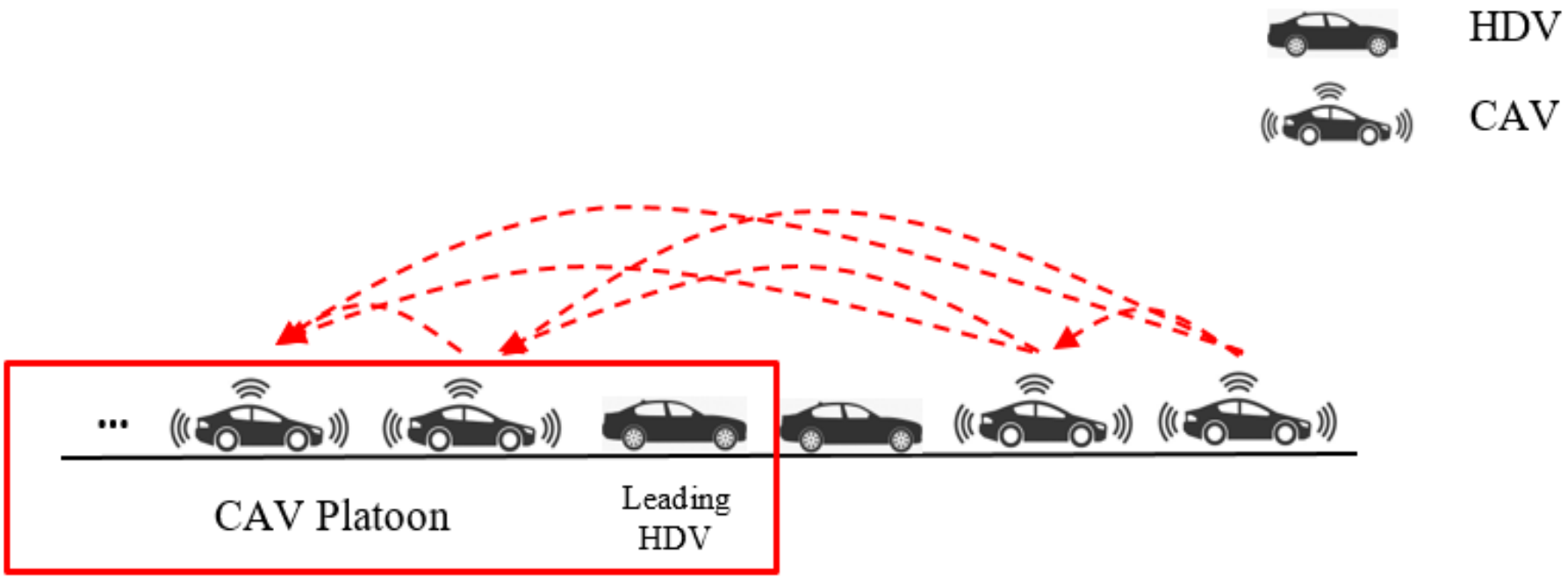
Outline

Problem Description

- Predict the leading Human-driven Vehicle's (HDV) trajectory for platoon control of CAVs.



1 Problem Description

2 Motivation
- Mixed Traffic Flow
- Data-driven Model

3 Data Set and Preprocessing

4 Model Building

5 Results

Motivation-Mixed Traffic Flow

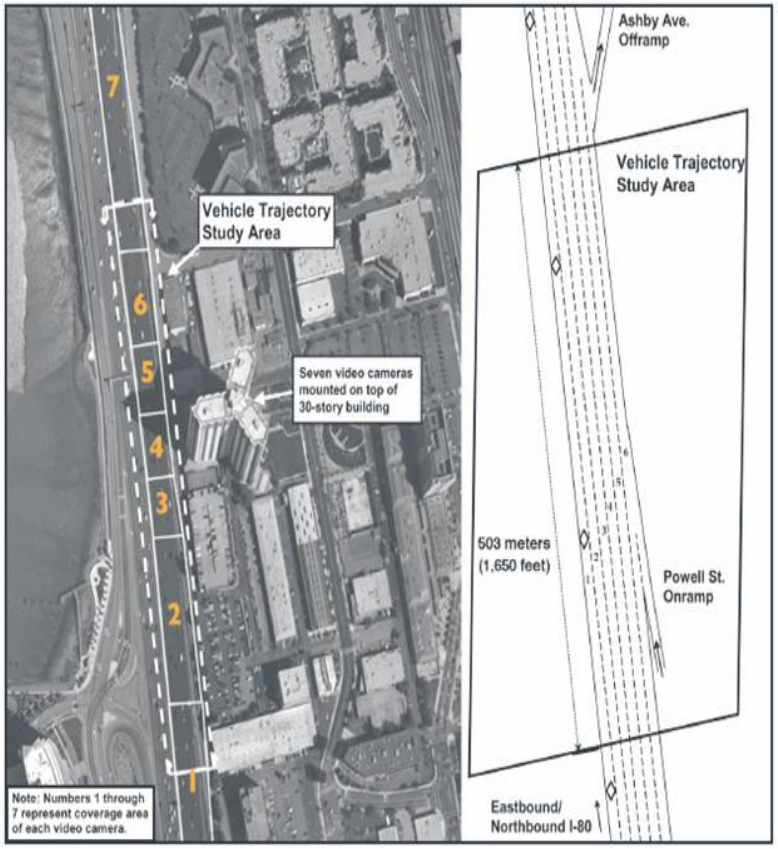
- Long transition period to a fully Connected and Autonomous Vehicle (CAV) environment.
  - All new vehicles will have the connectivity function until 2025 (GSMA, 2013).
  - 75% of vehicles will be autonomous until 2040 (IEEE, 2012).

Motivation-Data-driven Model

- Most vehicle trajectory prediction models are parsimonious.
  - Provide analytical conclusions and fast simulation speed.
  - Limited model flexibility and accuracy.
  - For example, car following models in traffic simulation studies rely on artificial parameters in empirical equations.
- Trajectory data from CAVs in the communication range can help to predict the HDV's trajectory.

Data Set and and Preprocessing

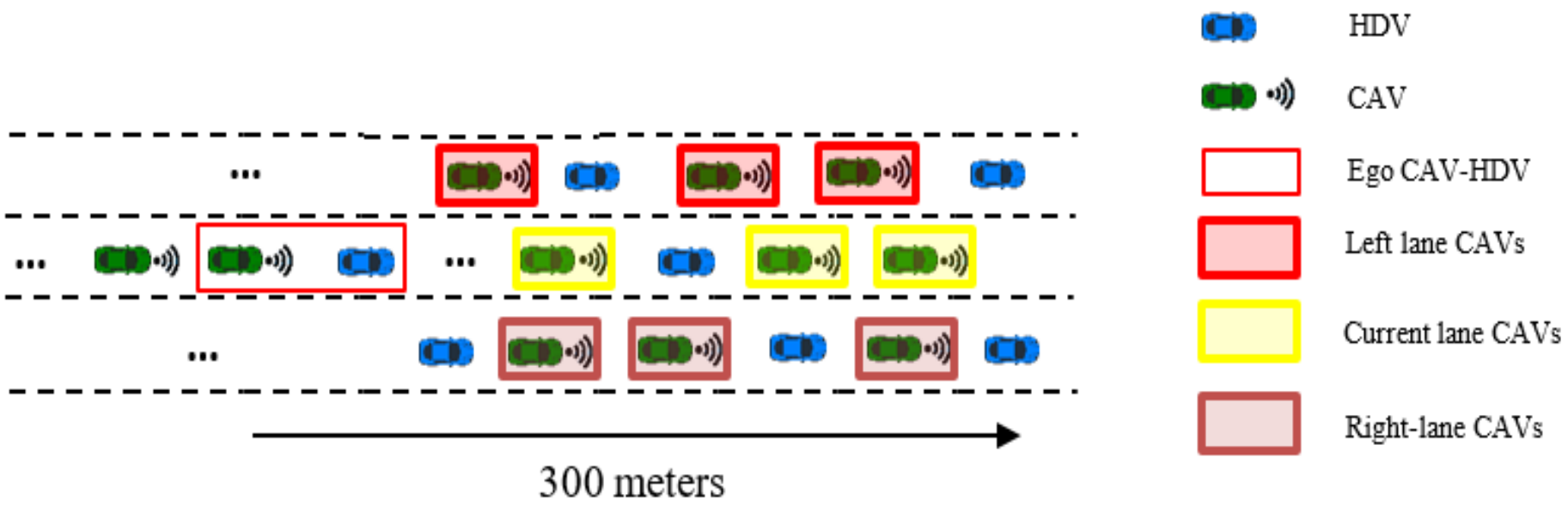
- Next Generation Simulation (NGSIM) Data Set:
  - 500 meters long, 4:00 PM-4:15 PM, 04/13/2005, I-80.
  - Lateral and longitudinal locations, VehID, Time Step, Velocity, Acceleration, Preceding VehID, LaneID by 10 Hz.
  - Reconstructed data were downloaded (Punzo et al., 2011).



[1]

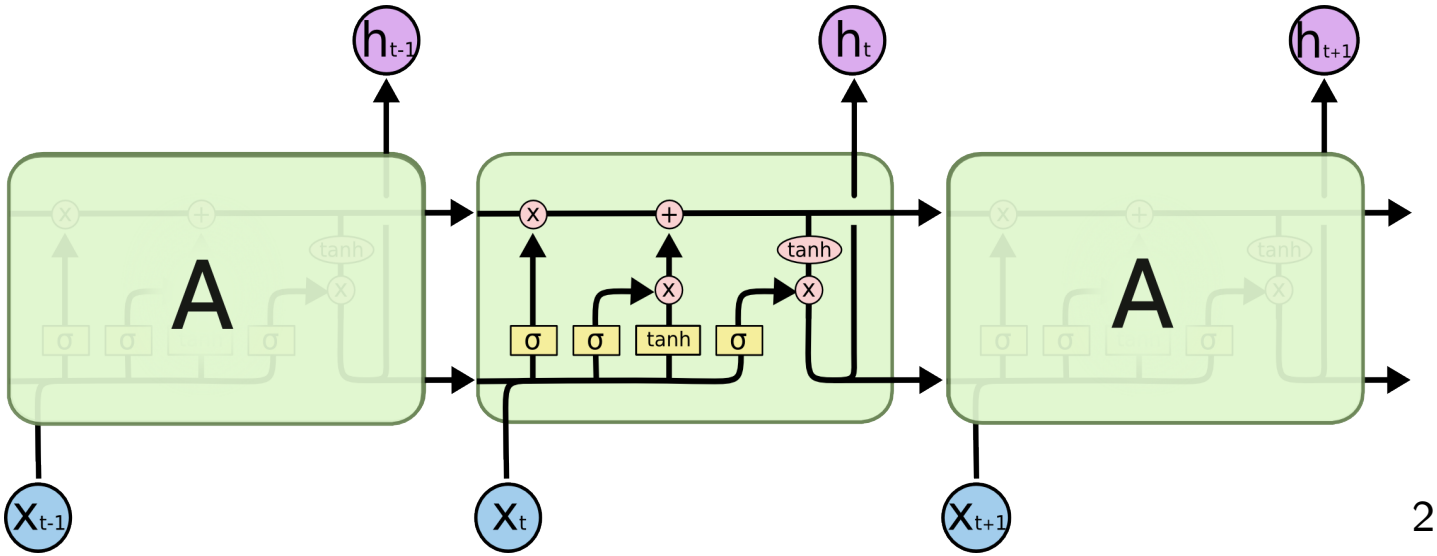
[1] https://www.fhwa.dot.gov/publications/research/operations/06137/index.cfm

Data Set and and Preprocessing



- Data Preprocessing Steps:
  - CAV Market Penetration Rate: 50%.
  - For lane 2, 3, and 4, find the Ego CAV and HDV pairs, and for each pair, find 3 CAVs in the front 300 meters from left, current, and right lanes separately.
  - Record the time step, lane location, speed, acceleration rate, vehicle length for the Ego CAV, the HDV and 9 CAVs.

Model Building



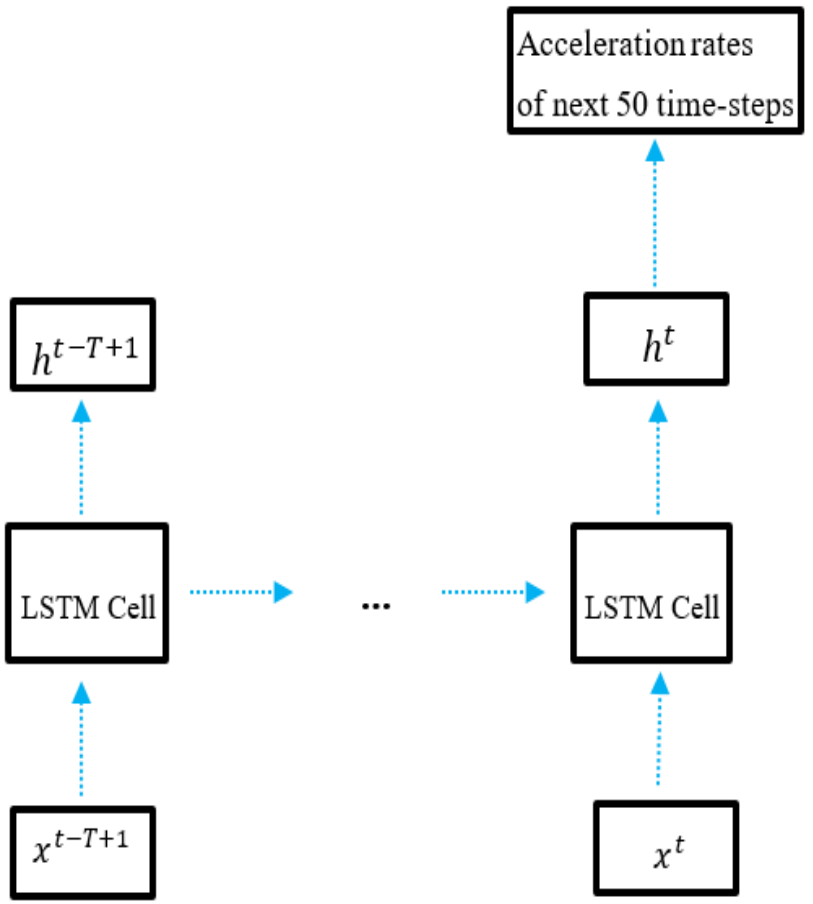
2

- The Long Short-term Memory Model (LSTM).
  - Designed for Sequencial Data.
  - Consists of LSTM Cells, each cell has an input gate, forget gate and output gate.
  - Automatically memorizing relevant spatial and temporal features extracted from previous vehicle states.

[2] http://colah.github.io/posts/2015-08-Understanding-LSTMs/

Model Building

- Experimental Environment:
  - GTX 1080, Tensorflow.
- LSTM Architecture:
  - Learning rate: 0.001.
  - LSTM cell number:100.
  - Mini-batch size: 100.
  - Hidden units in each cell: 400.
  - Early stopping threshold: 100.
- Data Set:
  - Training dataset size: 29376 X 7750.
  - Validation dataset size: 9792 X 7750.
  - Testing dataset size: 9792 X 7750.



$T = 100,$

$x^{t-i+1} \in \mathbb{R}^{77},\ i = 1, \ldots, 100,$

7 features × (9 CAVs + 1 Ego CAV + 1 HDV).

1. Problem Description
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   - LSTM Prediction Performances
   - CAV Platoon Control Performances

Results-LSTM Prediction Performances

Table 1: RMSE of Testing Data Sest.

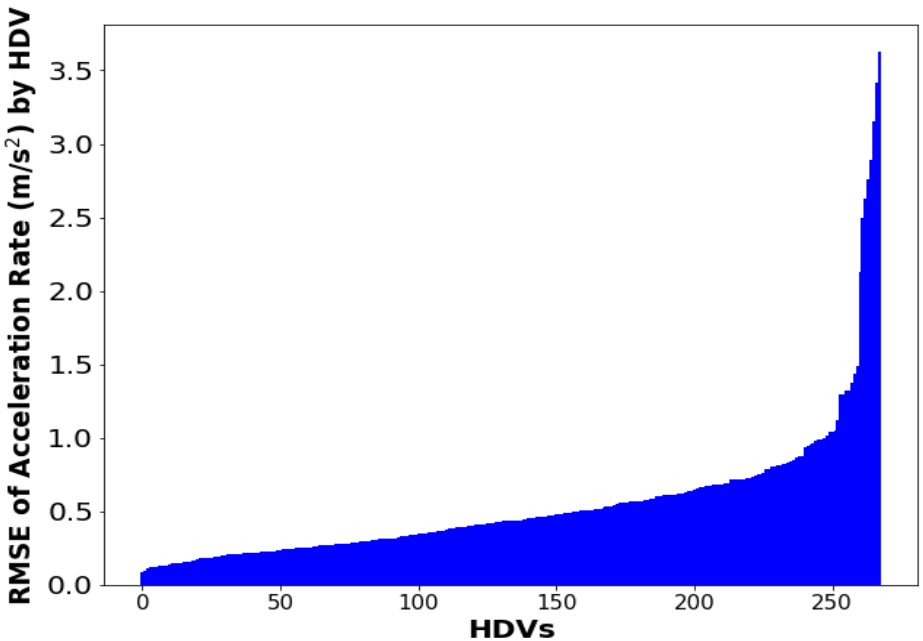
Number of CAVs	Prediction Steps	
	10	50
3 CAVs	0.67	0.72
9 CAVs	0.71	0.72

Table 2: Normalized RMSE of Testing Data Sest. (1-RMSE/MEAN)

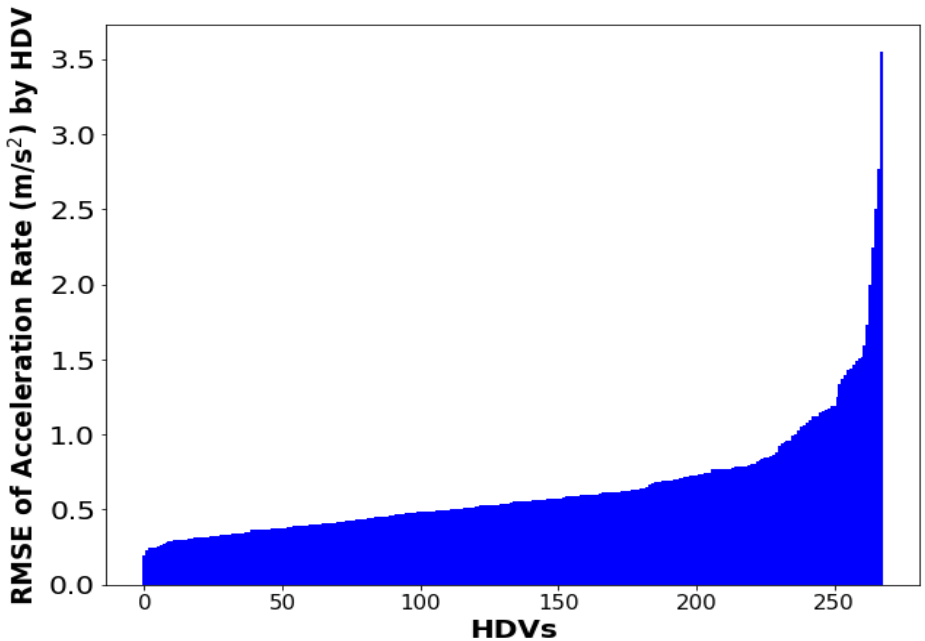
Number of CAVs	Prediction Steps	
	10	50
3 CAVs	95.40%	95.11%
9 CAVs	95.19%	95.01%

Results-LSTM Prediction Performances

RMSE by HDV ID (268 HDVs)



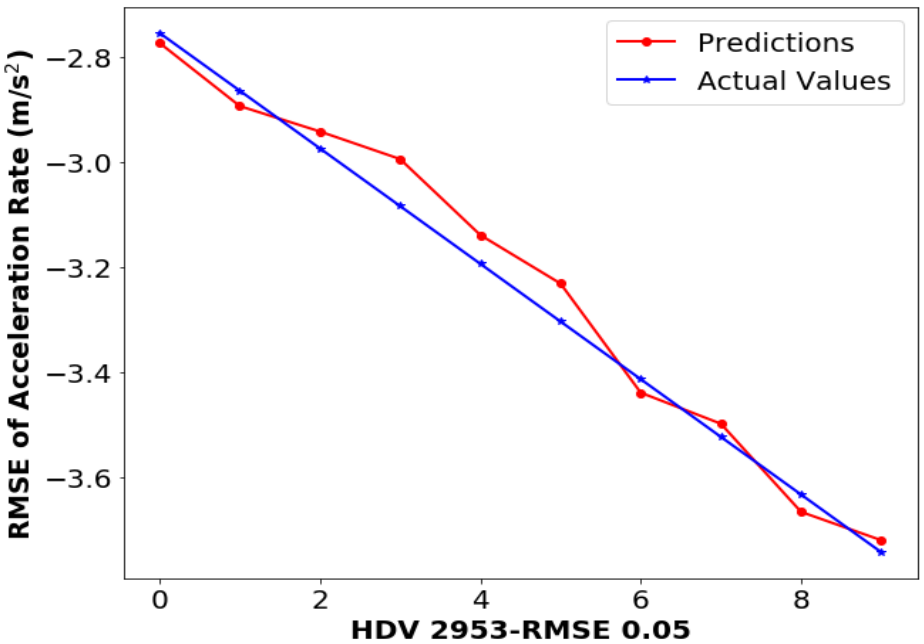
10 Prediction Steps with 3 CAVs

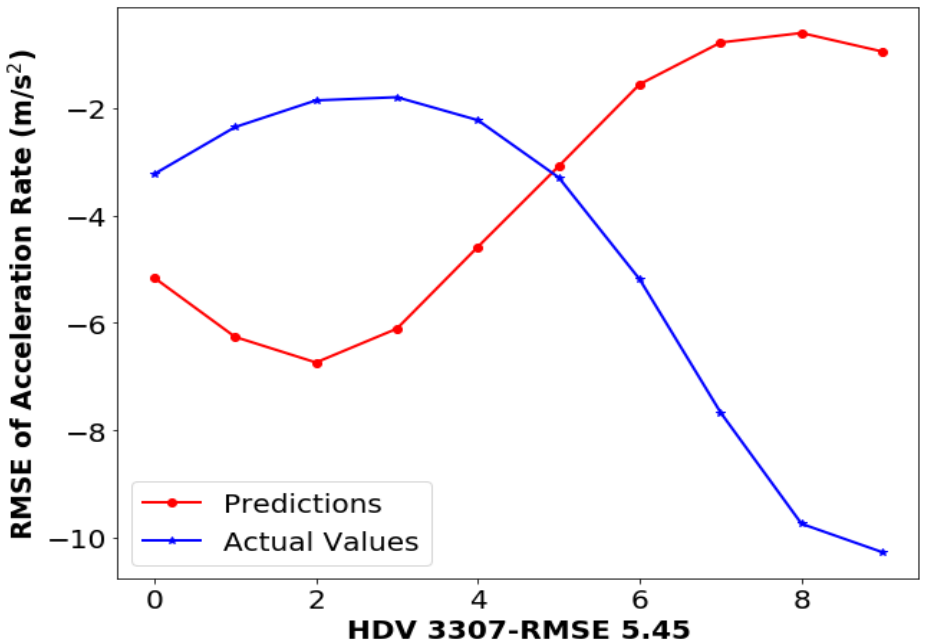


50 Prediction Steps with 3 CAVs

Results-LSTM Prediction Performances

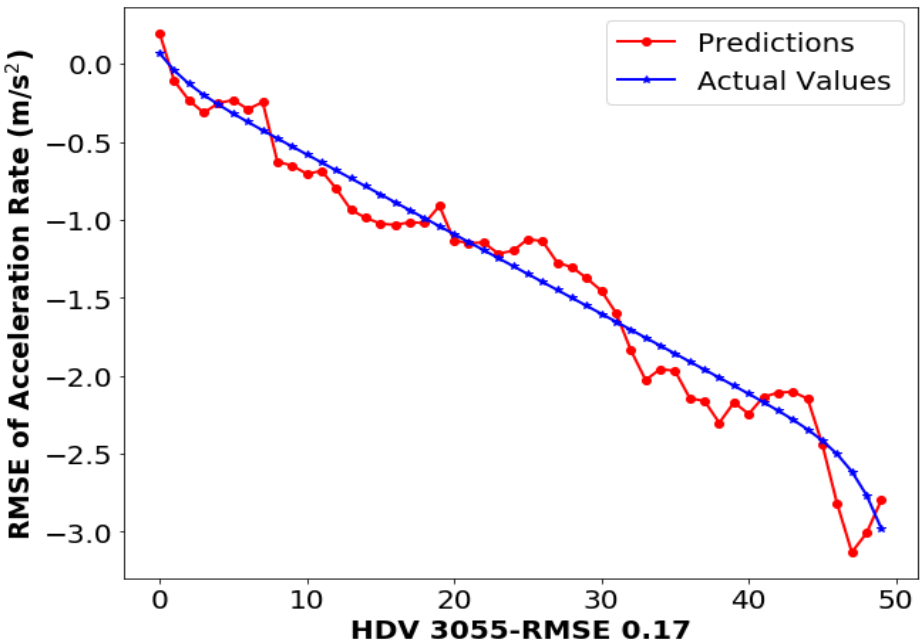
The Minimum and Maximum RMSEs for one Round of Prediction (10 Prediction Steps with 3 CAVs)

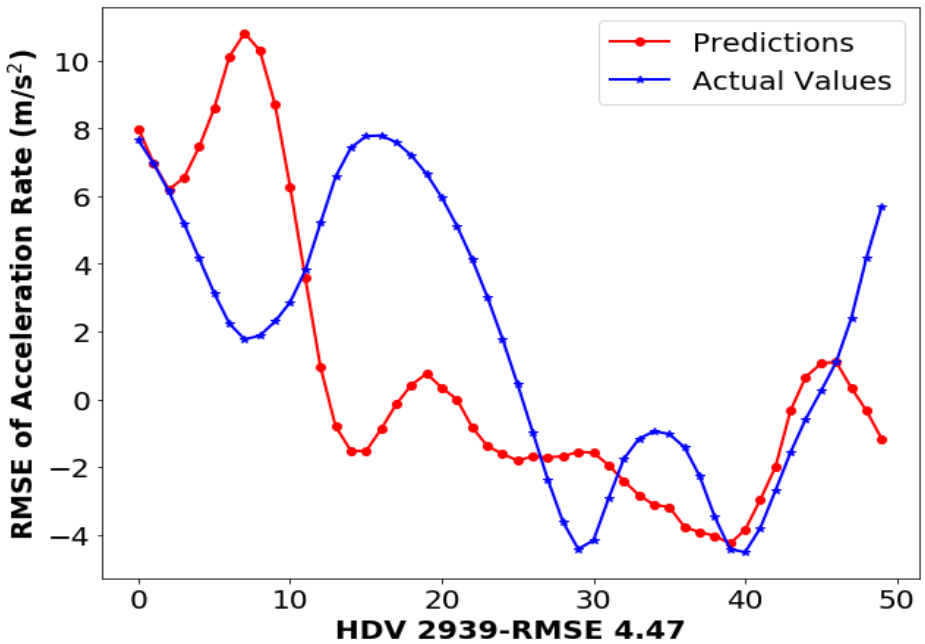




Results-LSTM Prediction Performances

The Minimum and Maximum RMSEs for one Round of Prediction (50 Prediction Steps with 3 CAVs)





Results-CAV Platoon Control Performances

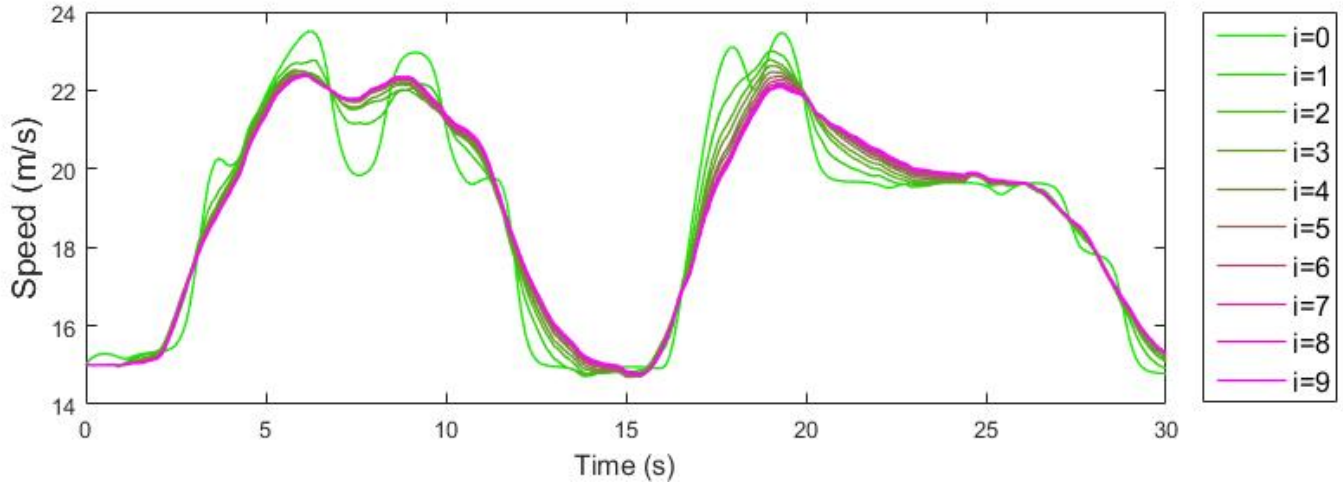
Select two representative HDVs, assume each is followed by a platoon of 9 CAVs, apply the P-step Model Predictive Control (MPC) (Gong and Du, 2018):

Table 3: RMSEs of Two HDVs.

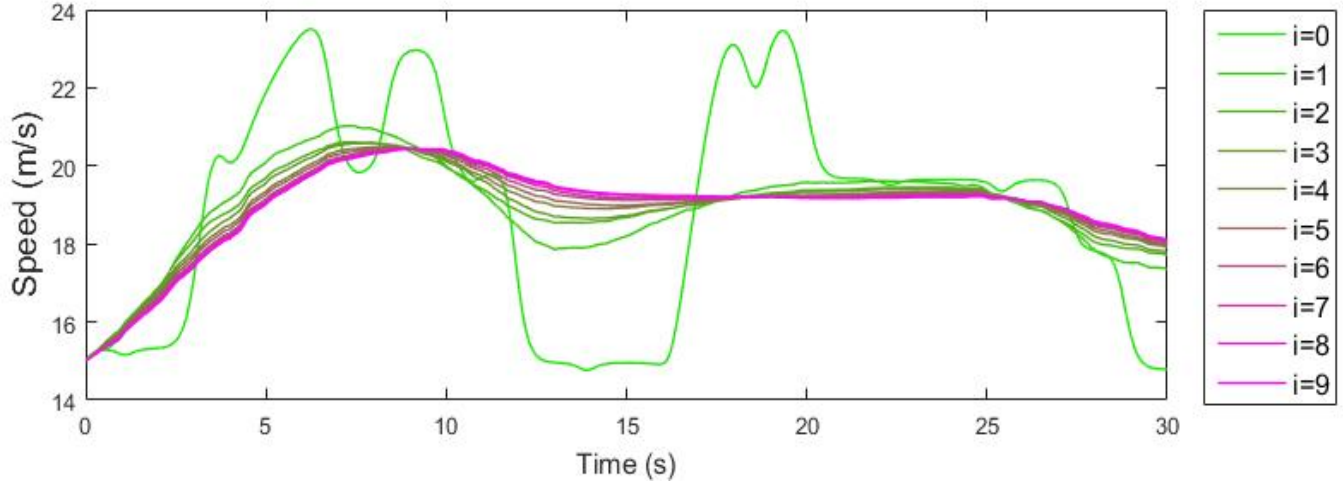
HDV	Prediction Steps	
	10	50
2973	0.56	0.64
3307	0.94	0.94

Results-CAV Platoon Control Performances

Impact of MPC on the speed of the CAV platoon following HDV 2973:



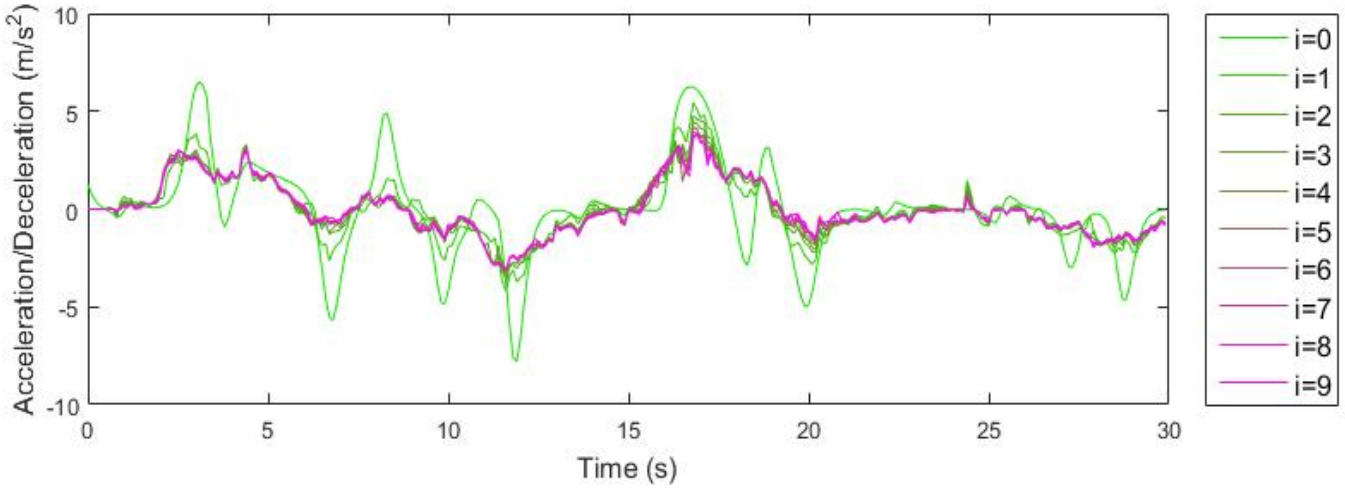
10-step predictions



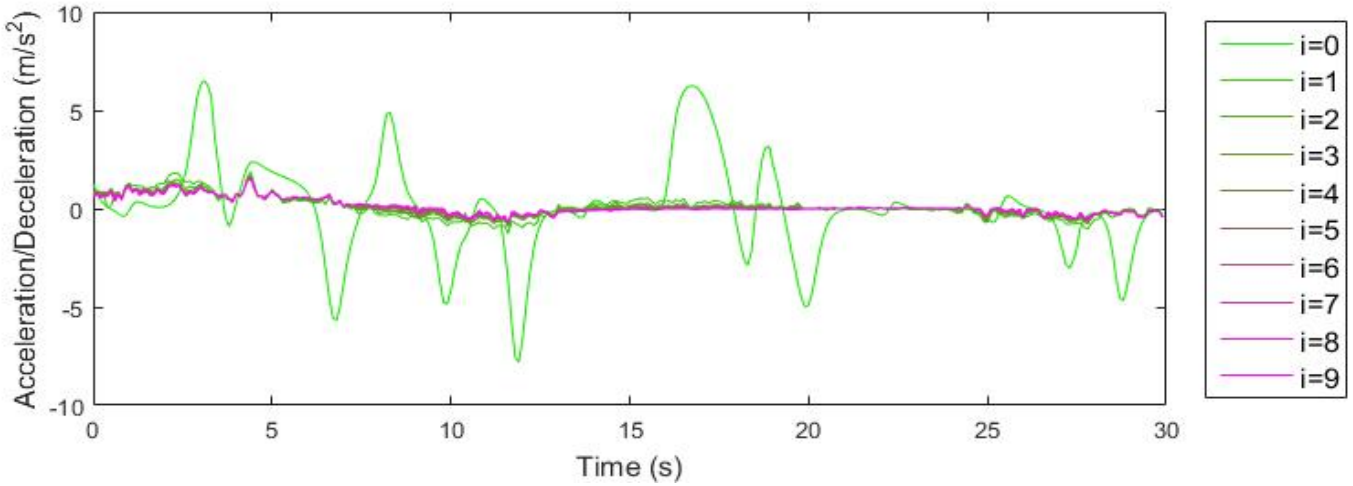
50-step predictions

Results-CAV Platoon Control Performances

Impact on the acceleration rate of the CAV platoon following HDV 2973:



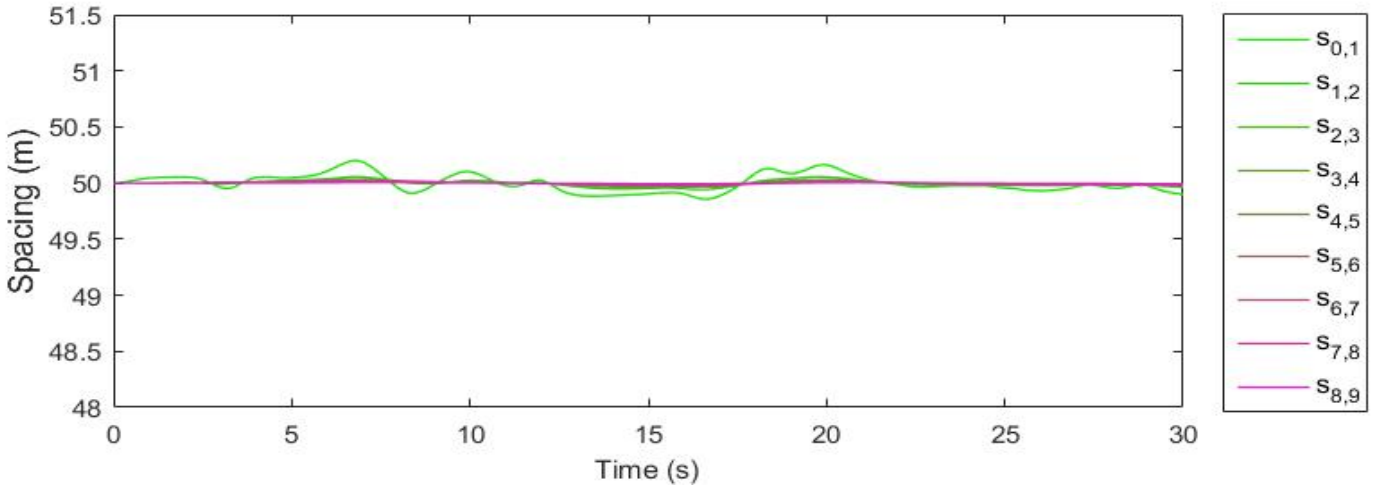
10-step predictions



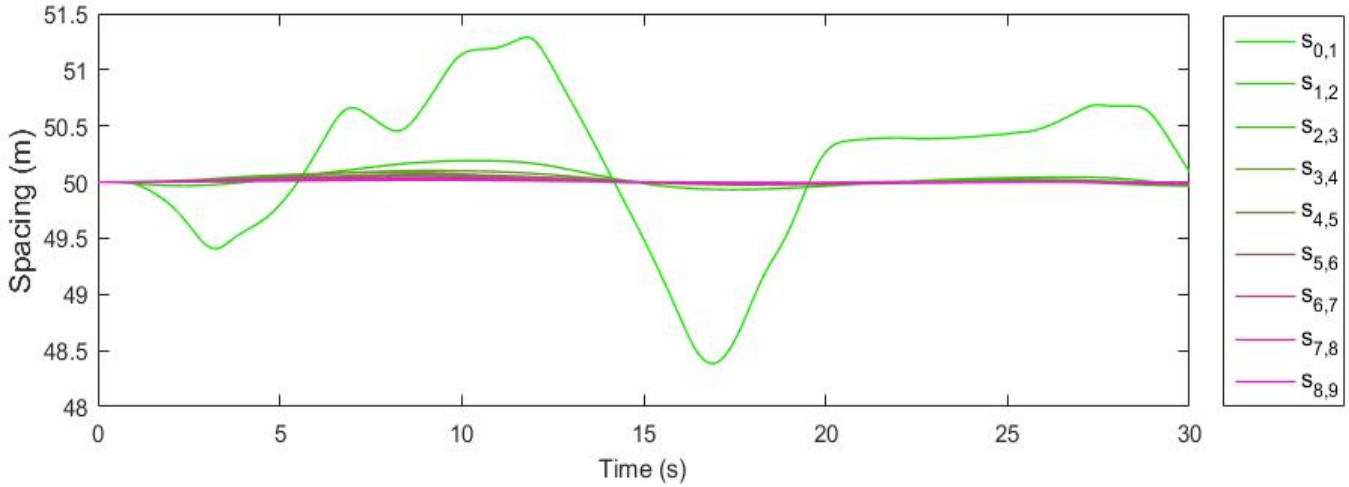
50-step predictions

Results-CAV Platoon Control Performances

Impact on the spacing of the CAV platoon following HDV 2973:



10-step predictions



50-step predictions

Results-CAV Platoon Control Performances

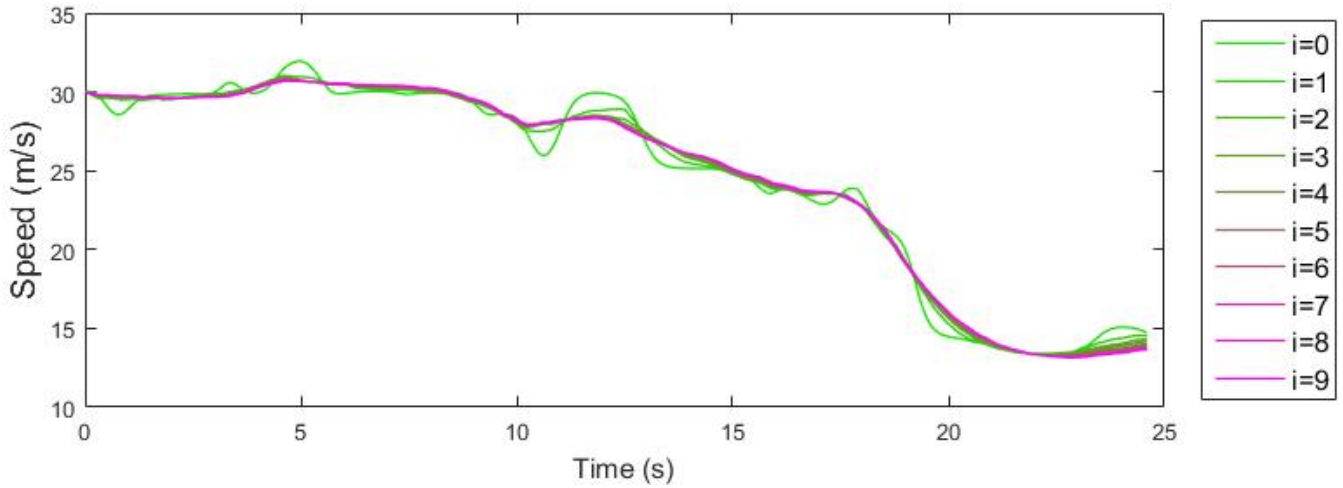
Select two representative HDVs, assume each is followed by a platoon of 9 CAVs, apply the P-step Model Predictive Control (MPC) (Gong and Du, 2018):

Table 4: RMSEs of Two HDVs.

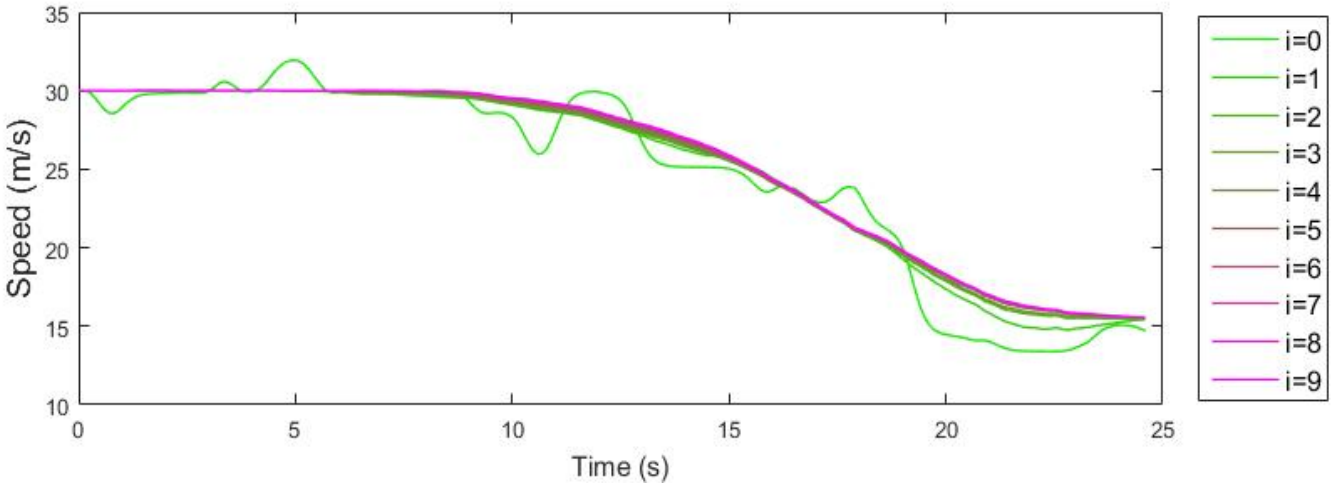
HDV	Prediction Steps	
	10	50
2973	0.56	0.64
3307	0.94	0.94

Results-CAV Platoon Control Performances

Impact of MPC on the speed of the CAV platoon following HDV 3307:



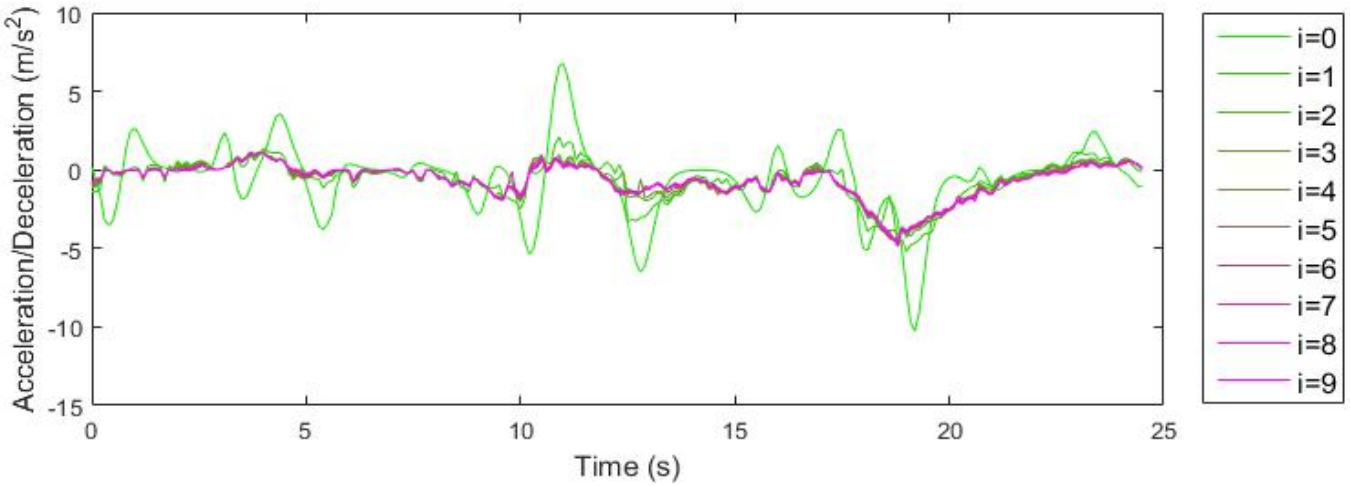
10-step predictions



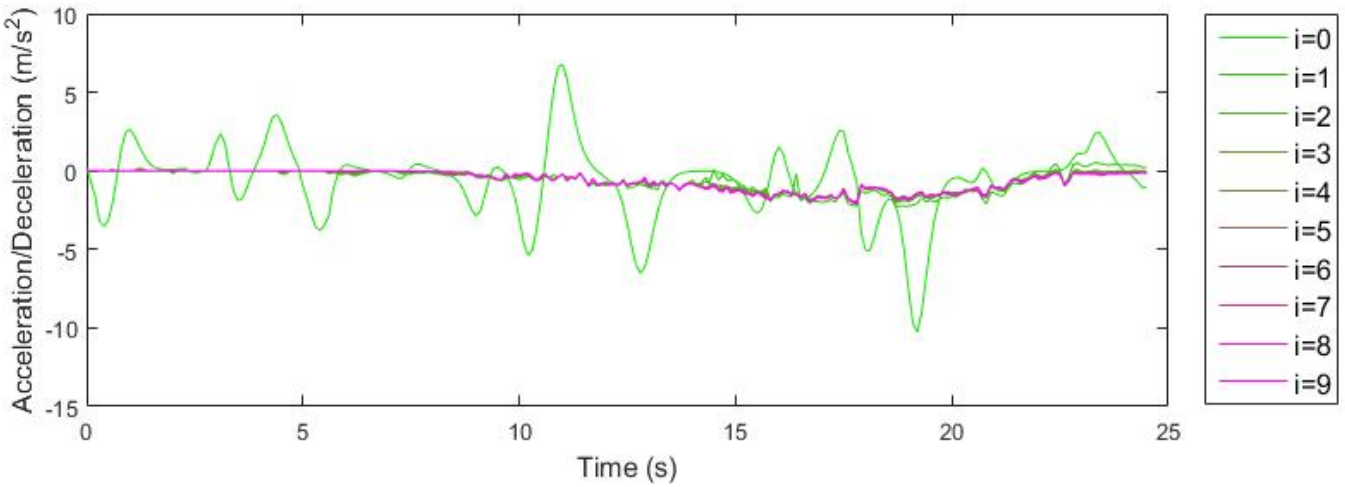
50-step predictions

Results-CAV Platoon Control Performances

Impact on the acceleration rate of the CAV platoon following HDV 3307:



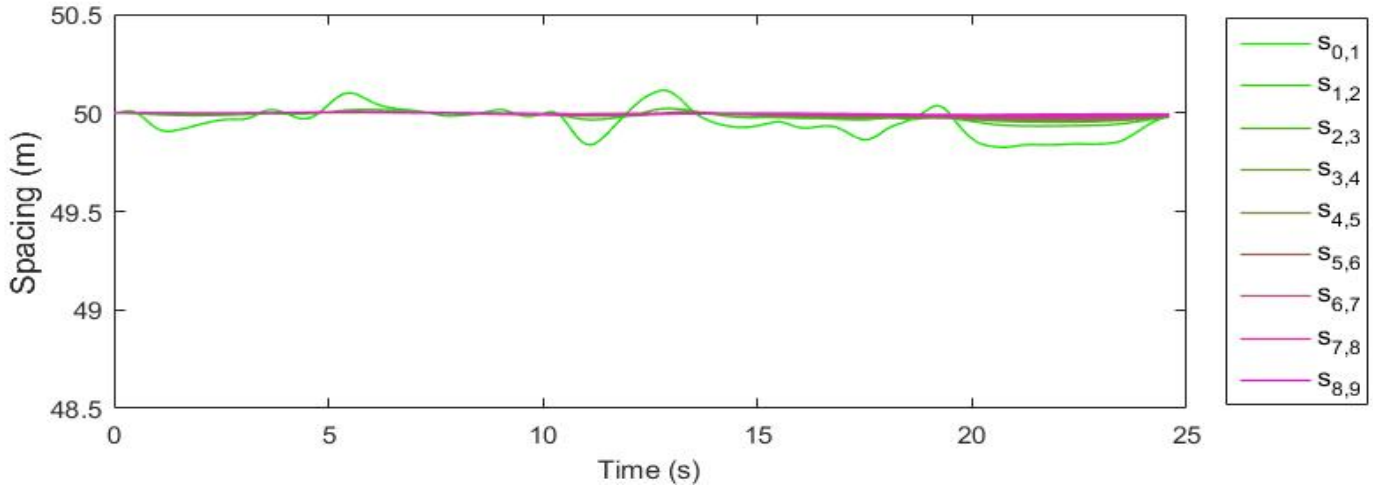
10-step predictions



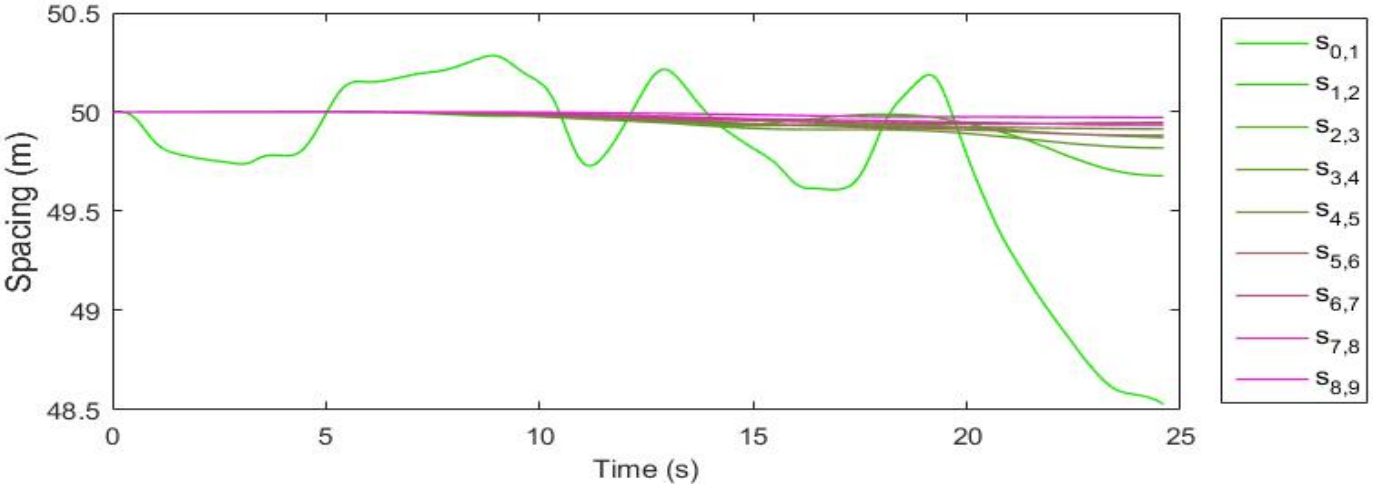
50-step predictions

Results-CAV Platoon Control Performances

Impact on the spacing of the CAV platoon following HDV 3307:



10-step predictions



50-step predictions

Summary

- Contributions
  - Utilized information from multiple vehicles to predict the HDV's acceleration rates.
  - Applied the state-of-the-art LSTM deep learning model for multiple-step-ahead predictions.
  - Based on our predictions, MPC Control can ensure both transient traffic smoothness and asymptotic stability of the CAV platoon.
- Limitations
  - Assumption of "connected".
  - Assumption of "automated".

Next Steps

- Further clean the dataset.
- Build the CNN-LSTM model.
- Test other platoon control algorithms.
- Evaluate the performances under different CAV MPRs, CV communication ranges and delay and so on.
- Predict a distribution of the acceleration rate and capture the uncertainty.

References

- GSMA, 2013. Eevery New Car Connected by 2025 as Embedded Mobile Mobile Technology Drives Growth of Connected Car Market.
- IEEE, 2012. https://www.ieee.org/about/news/2012/5september-2-2012.html (accessed 6.1.18).
- Punzo, V., Borzacchiello, M.T. and Ciuffo, B., 2011. On the assessment of vehicle trajectory data accuracy and application to the Next Generation SIMulation (NGSIM) program data. Transportation Research Part C: Emerging Technologies, 19(6), pp.1243-1262.
- Siyuan Gong and Lili Du. 2018. Cooperative Platoon Control for a Mixed Traffic Flow Including Human Drive Vehicles and Connected and Autonomous Vehicles. Transportation Research Part B: Methodological. Accepted.

Thanks for your attentions!
Any questions?