CAREER: Multi-Resolution Model and Context Aware Information and Networking for Cooperative Vehicle Efficiency and Safety Systems

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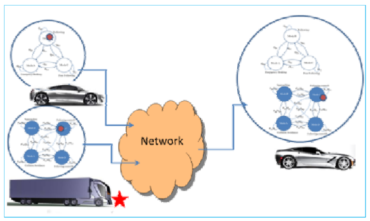
Motivation and Problem Statement

- Connected vehicles rely on V2V networks. Scalability is one of the main challenges, preventing rich collaboration and sensor information sharing.
- Proposed approach:
  - replace data communication and networking
  - with model communication and networking
- Generating ***precise models*** is the first key task to realize this idea.
- ***Bayesian Non-Parametric Inference*** approaches are studied for adaptive model construction.
- A scheme based on extended Switching Linear Dynamical Systems-Hierarchical Dirichlet Process-Hidden Markov Model (***SLDS-HDP-HMM***) is considered.
- The resulting stochastic hybrid system (**SHS**) model, which tracks the joint vehicle-driver behavior, is continuously updated by adding/removing necessary/unnecessary states on the fly.



Background Theory of the Modeling Framework

SLDS-HDP-HMM and AR-HDP-HMM (Theoretically Infinite-State HMM Models)

$$\nu_k|\lambda \sim Beta(1,\lambda) \quad for\ k = 1,2,\ldots$$

$$\varphi_k = \nu_k \prod_{h=1}^{k-1}(1-\nu_h) \quad for\ k = 1,2,\ldots$$

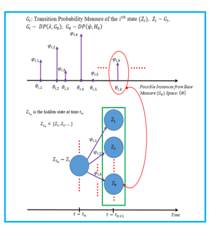
$$\Phi \sim GEM(\lambda) \Leftrightarrow \Phi = \{\varphi_1, \varphi_2, \ldots\}, \varphi_k \in (0,1), (\forall k = 1,2,\ldots), \textstyle\sum_{k=1}^{\infty}\varphi_k = 1$$

$$G_i \sim DP(\lambda, G_0) \Leftrightarrow G_i = \sum_{k=1}^{\infty}\varphi_{i,k}\delta_{\theta_{i,k}} \quad \left\{\begin{matrix}\theta_{i,k}|G_0 \sim G_0\\ \{\varphi_{i,:}\} \sim GEM(\lambda)\end{matrix}\right\} \ for\ k = 1,2,\ldots$$

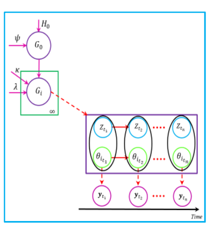
$$G_0 \sim DP(\psi, H_0)$$

$$x_{t_n} = A^{(z_{t_n})}x_{t_{n-1}} + e(z_{t_n})$$

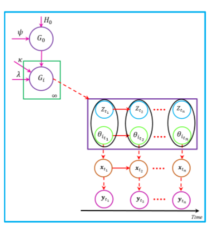
$$y_{t_n} = Cx_{t_n} + g(t_n)$$



HDP-HMM

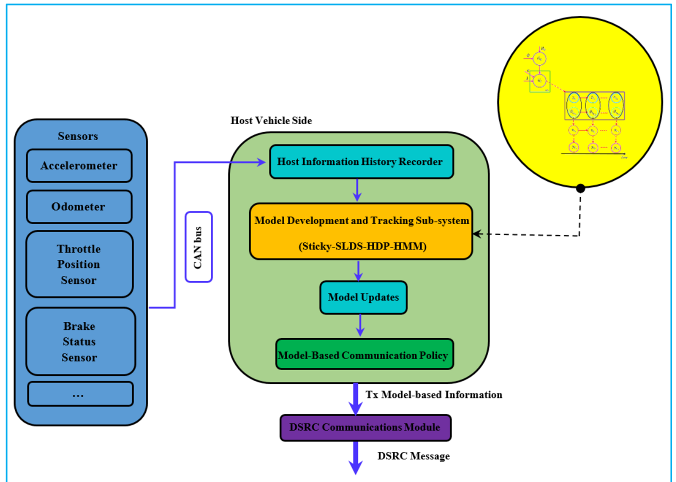


Sticky-AR-HDP-HMM[2]

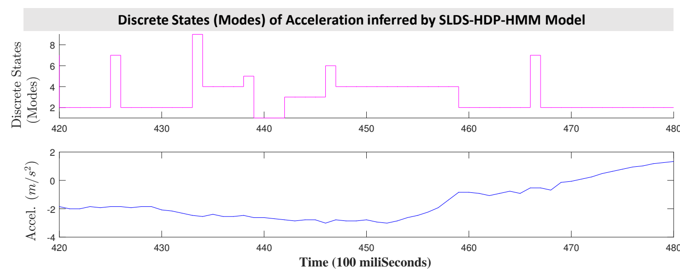


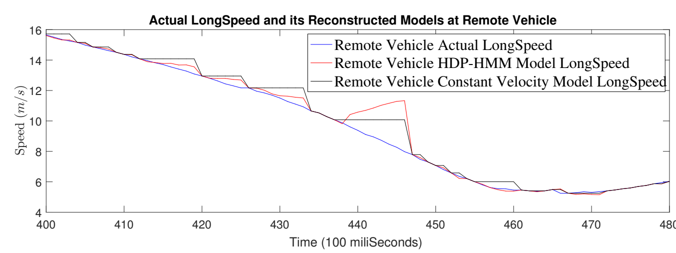
Sticky-SLDS-HDP-HMM [2]

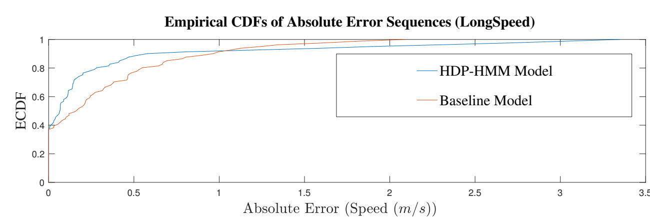
System-Level Architecture



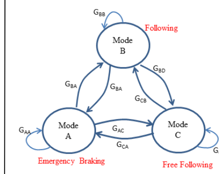
Inference Results





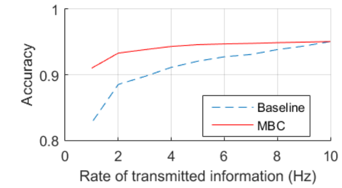


Other Examples and Applications



A simple vehicle movement model

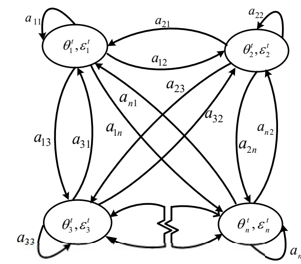
Use MBC[4]

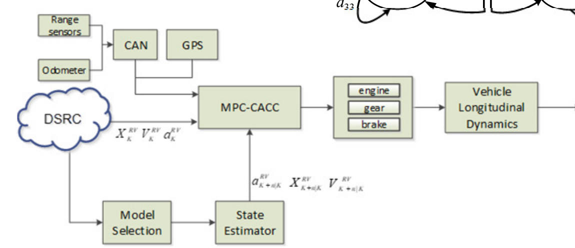


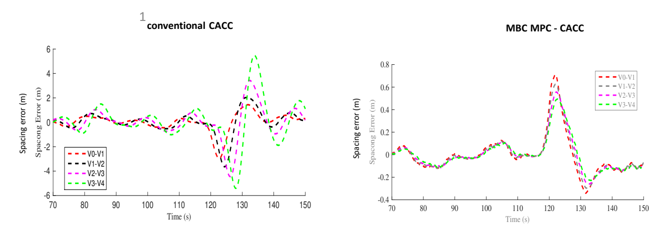
Accuracy vs Rate for Baseline and MBC methods, assuming PER =0

Example Application: Cooperative Adaptive Cruise Control

Learn and update model : Use a switched system structure such as HMM + ARX hybrid system.
Control: Use exchanged models in model-predictive CACC controllers.
Result is an order of magnitude improvement in spacing error in CACC[1].







5 vehicle platoon - CACC

References

[1] E. Moradi-Pari, H Nourkhiz Mahjoub , H Kazemi, Y. P. Fallah," Utilizing Model-Based Communication and Control for Cooperative Automated Vehicle Applications", to appear in IEEE Trans. On Intelligent Vehicles, 2017
[2] E. Fox, "Bayesian nonparametric learning of complex dynamical phenomena," Ph.D. dissertation, Massachusetts Inst. Technol., Cambridge, MA, July 2009.
[3] E. Fox, E. Sudderth, M. Jordan, and A. Willsky, "Nonparametric Bayesian learning of switching dynamical systems," in Proc. Advances in Neural Information Processing Systems, 2009, vol. 21, pp. 457–464.
[4] Y.P. Fallah, "A Model-Based Communication Approach for Distributed and Connected Vehicle Safety Systems", in proc. IEEE Systems Conference, 2016
[6] Y.P. Fallah, M.K. Khandani, "Context and Network Aware Communication for Connected Vehicle Safety Applications", in IEEE Intelligent Transportation Systems Magazine, 2016

Other sponsors and collaborators: General Motors, Toyota ITC