Perceptive Stochastic Coordination in Mass Platoons of Automated Vehicles

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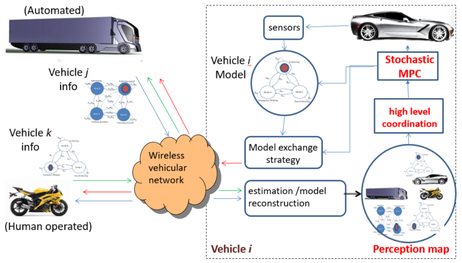
Motivation and Problem Statement

- This research aims to push the boundaries of coordinated operation of a large network of connected and automated vehicles (CAVs) in a mixed environment of manned and automated vehicles, through the concept of *perceptive stochastic coordination*.
- Objective: Large-scale and Highly Efficient Operation of **Mass Platoons**
- Approach:
  - Vehicle movements will be modeled as stochastic hybrid systems and associated models utilized in a stochastic model predictive control (SMPC) setting.
  - Both communication and control will be model-based and designed considering the utilities and behavior of the other component.



Coordinated control, based on SMPC, uses models of agents and perception maps acquired through sensors and V2V communication.

Challenges and Approaches

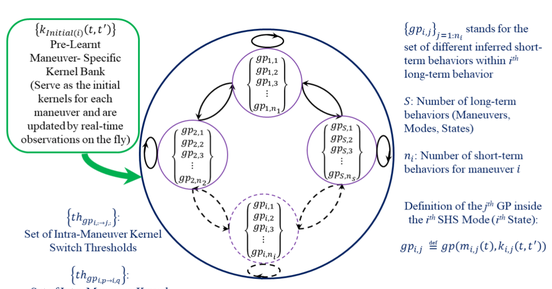
- Collaborative work with our *German partners in an NSF-DFG joint proposal:*
  - *University of Koblenz Landau, Hamburg University of Technology*
- Setting: Network of CAVs, where information exchange is in the form of complex models of behavior over an unstructured network (broadcast vehicular networks), and where control is performed in a stochastic model predictive setting.

Challenges

- **Coordination of a massive platoon of CAVs**: exacerbated by the interference of human actors in operation of CAV systems.
- **Communication of massive CAV platoons**: system performance quickly deteriorates in the presence of communication issues or excessive application demands.

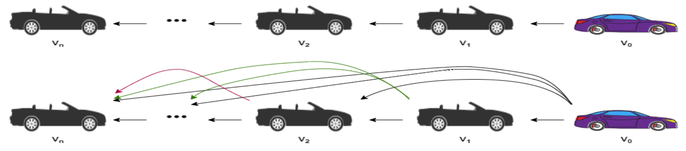
Methods to address the challenges

- Main approach: joint optimization of control and communication aspects, and utilizing the concepts of ***event-triggered control and cost-triggered communication***.
- Utilizing stochastic hybrid system (SHS) models, based on a non-parametric Bayesian learning approach, i.e., multi-variate stochastic Gaussian process, to create a
  - ***SHS-based perception of the CAV ecosystem*** and to
  - ***coordinate control of CAVs based on this perception in a stochastic model predictive control framework***.



Multi-modal GP based model

Research Progress



Adaptive Cruise Control (ACC) vs Cooperative ACC (CACC): information availability and connectivity.
A platoon will build and expand the CACC concept

- **Modeling and Communication-Aware Stochastic MPC Design for Mass Platooning**

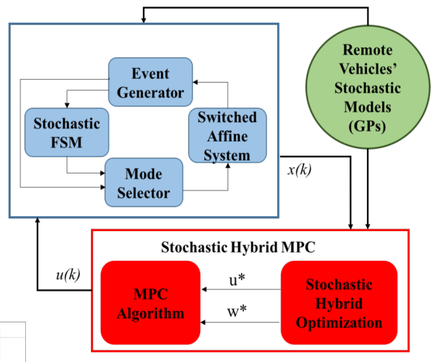
We are developing a predictive control system for vehicles in a platoon that utilizes information of several surrounding vehicles to predict traffic situations and take early driving actions.

System is modeled as a discrete hybrid stochastic automata (DHSA).

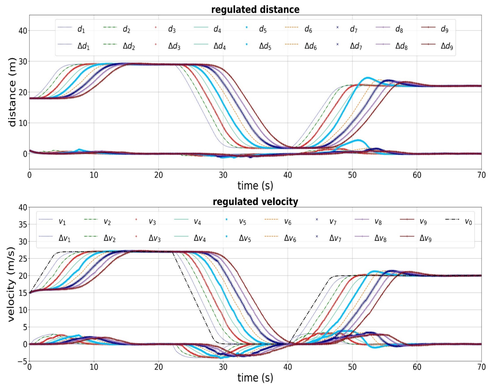
A discrete hybrid stochastic MPC is designed for the DHSA model considering two operating modes: free following, emergency braking.

The platoon operates safely with low communication rates and communication loss.

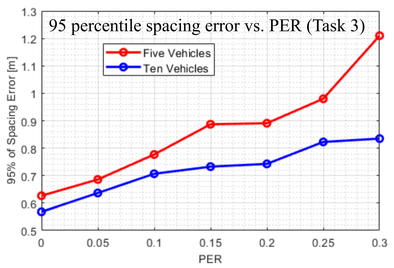
During sudden deceleration, vehicles may operate in emergency braking mode for safety.



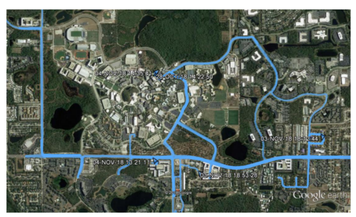
Interconnection of the DHSA model components and the hybrid MPC scheme (Tasks 1, 3)

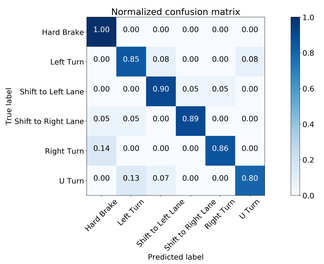


Illustrative results on the proposed discrete hybrid stochastic MPC performance for a platoon of 10 vehicles with low communication rate subject to communication loss (Task 1)



D2CAV dataset, driving maneuvers to be used for modeling: (https://github.com/groverdivas/D2CAV)
A random-forest classifier also trained for automated labeling of additional data





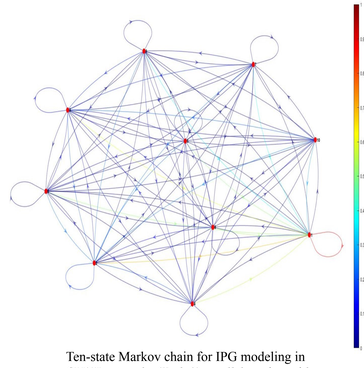
Planned for year 2:

- Time-triggered stochastic MPC design: devise a stochastic MPC framework to *improve driving efficiency, safe following and safe lane change of the entire traffic.*
- Mixed vehicle/driver hybrid models for perception maps using D2CAV dataset.

- **Control-Aware Communication and Networking Strategies for Hybrid Models**
  - Design of a probabilistic communication/connectivity model for the wireless links (for CV2X and DSRC vehicular networks).
  - Design of a control-aware sampling/communication logic (year 2)

A Markov chain model was derived through analysis of Inter Packet Gap (IPG) based on our realistic ns-3 simulations (from a project sponsored by Ford).

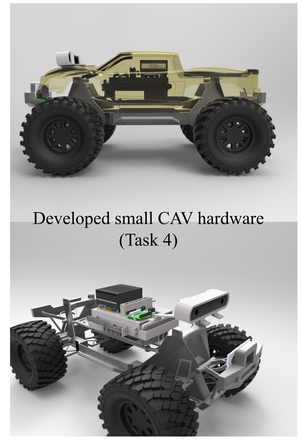
Model: ten states and their transition probability matrix => expectation for the next received packet at each state, which can be used for control purposes.



Ten-state Markov chain for IPG modeling in CV2X networks (Task 3) – collaboration with Univ. Koblenz Landau

Simulation and Experimentation Platform

- Large scale tests: tests with mass platoons of hundreds of vehicles will be conducted using a high fidelity co-simulator tool built by extending CARLA (in-progress)
- Road tests: 3-D printed housing and mechanical parts for modifying a Traxxas 1/5th scale vehicle is now complete, assembled with Nvidia Xavier, ZED depth sensors, TI radar, communication modules and controllers.



Developed small CAV hardware (Task 4)

Broader Impact

As part of our BPC plan:

- Graduate and undergraduate students were recruited at UCF from underrepresented (Hispanic) groups
- Undergrad researchers were hired through UCF EXCEL Program
- We have started recruiting students for an eAV club – combined with f1tenth effort – (stalled in 2020 due to the pandemic).
- UGA PI recruited two female undergraduates, one of whom started her graduate studies (MS in ECE) in Fall 2020.
- UGA PI has initiated contacts with Hilsman school (a high poverty middle school) to give workshops with the eventual goal of attracting students into a summer program.

Products

[1] https://github.com/groverdivas/D2CAV (Driving Maneuver Dataset)

[2] B. Toghi, D. Grover, M. Razzaghpour, R. Jain, R. Valiente, M. Zaman, G. Shah, Y.P. Fallah, "A Maneuver-based Urban Driving Dataset and Model for Cooperative Vehicle Applications," 2020 IEEE 3rd Connected and Automated Vehicles Symposium (CAVS), 2020, pp. 1-6, doi: 10.1109/CAVS51000.2020.9334665