Adaptive Intelligence for Cyber-Physical Automotive Active Safety System Design and Evaluation (CPS Award #: 1544814)

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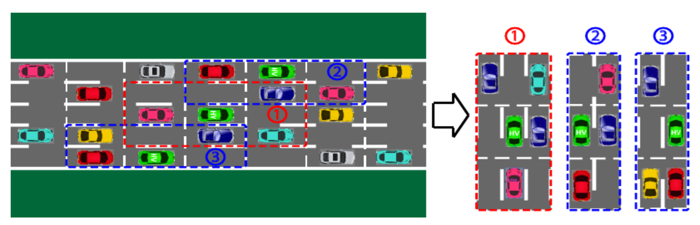
Driver-Based Reinforcement Learning Traffic Navigation



MDP State Decomposition

Additions to Traffic System Modeling

✓New driving scenarios with multi-cell state lane boundary constraints

✓Modelling road curvature affects

Deep Reinforcement Learning Features

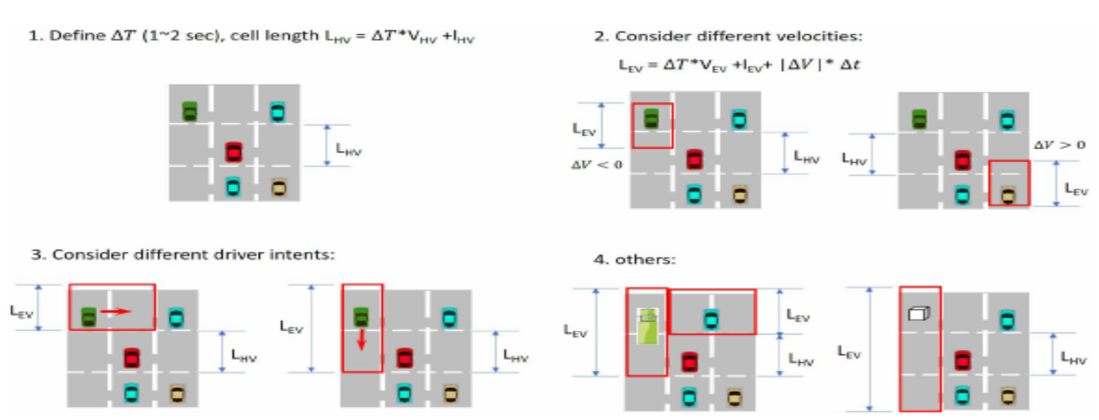
✓Traffic Configuration

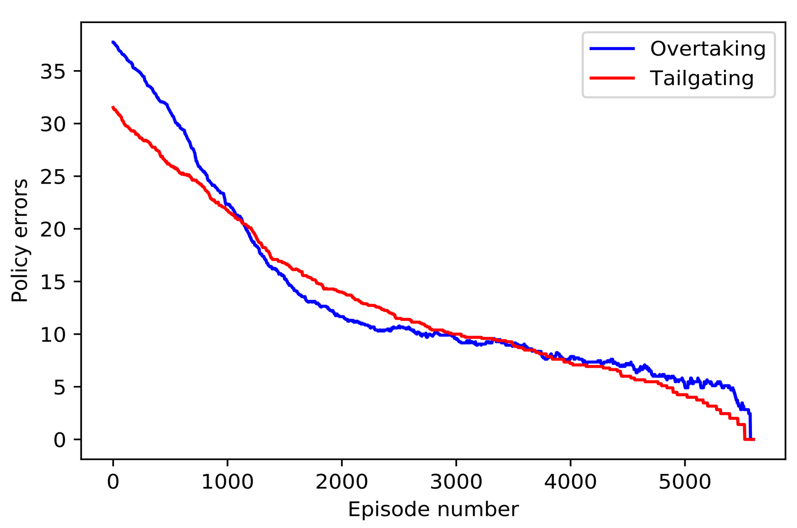
✓Overtaking Strategy

✓Action Features

✓Tailgating

✓Collisions





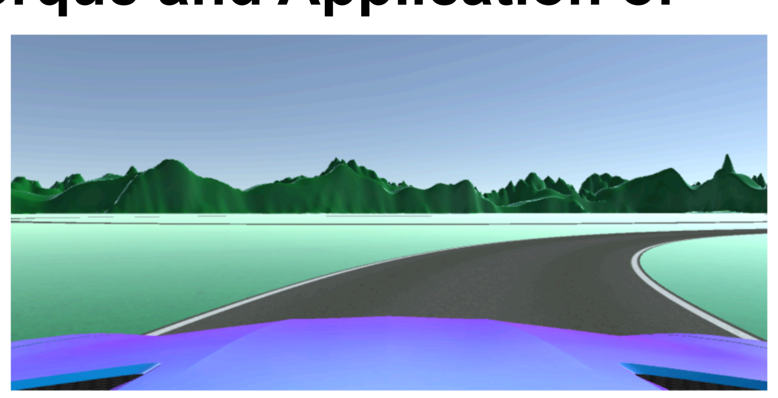
Error Rate While Learning Driving Strategies

Path Planning for Lane Switching

✓Use of 4th-order Bezier curve for handling maximum curvature constraints and new controller led to:

- ✓ C^2 –continuous, minimally-jerky paths with bounded curvature
- ✓Allows tracking with smaller curvature, higher smoothness, at lower speeds
- ✓Faster learning convergence

Estimating Human Driving Torque and Application of Two-Point Visual Control



Human driver control model driving in simulation environment

- System identification using Joint EKF to extract steering angle and angular velocity are used to estimate inertial and damping parameters
- Human driving data from a road circuit (a) allows a proportional-integral observer to estimate the torque (b) and test parametric and non-parametric control models (c)
- Application of two-point visual control model to driving
  - Simulation & Experimental Environments
  - Lane & Front-Vehicle Following Scenarios

Human driver control model driving in experimental environment using AutoRally platform

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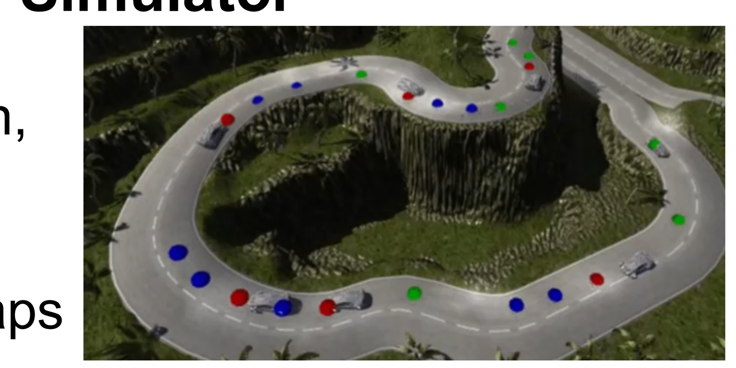
Objective

Improve capabilities of automotive advanced driver assistance systems (ADAS) by taking into account the physical and psychological interactions between the driver, the vehicle, ADAS, traffic, and the environment.

Research Approach

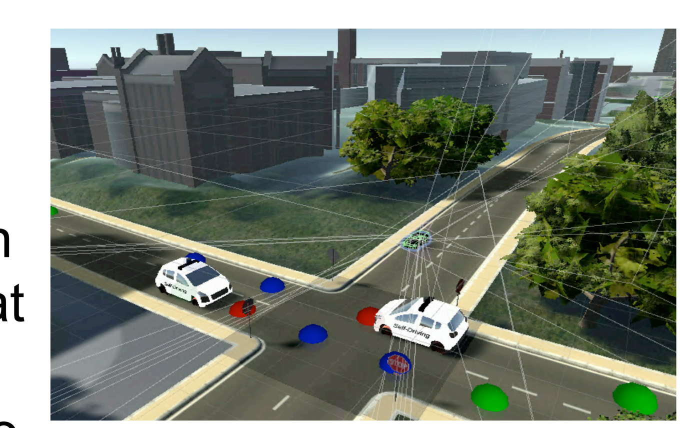
- Putting the focus on human driving behaviors
- Better modeling of the human driver within control systems and for behavioral decision making
- Creating a simulation environment for validation and human-in-the-loop testing of ADAS systems

Development of the Driving Simulator



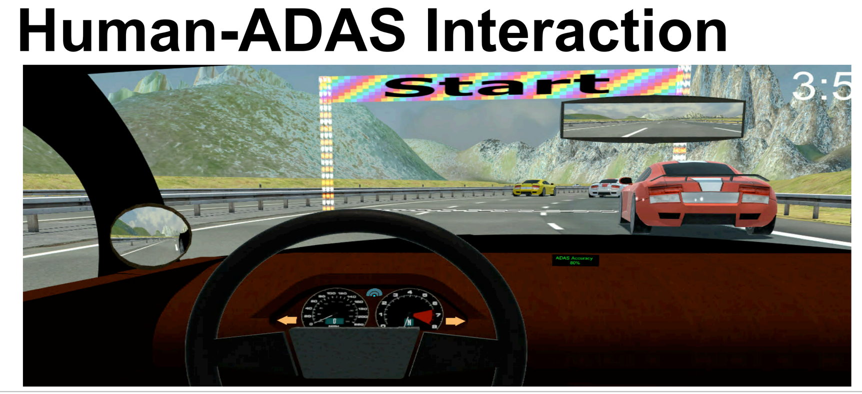
- Multi-car traffic
- Realistic scenarios with terrain, weather, steering-column feedback torque, and smooth control, all built on satellite maps and CAD models of campus
- ADAS: Emergency Braking, Adaptive Cruise Control, Blind Spot Detection, Lane-Departure Detection, Crash Sensing

Human Driver Expectations of Autonomous Cars



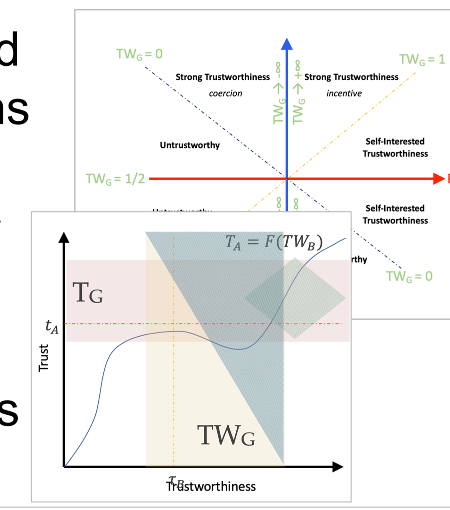
- 29 participants (ages 18-60, 25% female), between and within subjects
- Multiple interactions with human and autonomously driven cars at stop-sign controlled junctions
- Highly-realistic campus scenario
- Tested an instrument for validation of simulator
- Tested an instrument for testing driving and interaction expectations related to human and autonomously driven cars
- Planned random failures of autonomous cars to test trust

Human-ADAS Interaction



- Complex parallel traffic navigation
- Highway scenario with adverse weather
- Imperfect ADAS with expectation setting

Interdependence Theory for Human-AI Trust Interactions



- Trust interactions can be pre-specified and designed to elicit certain interdependence and control relations
- Competitive-irrational behavior and anticipated interaction outcomes can be detected from affect or estimated from behavior and trust-based design modified accordingly
- Systems can judge the trustworthiness of their users and how much their users trust them

Future Work

- Validation and testing of ADAS systems on the driving simulator
- Researching the affects of transparency and trust between the human and the assistive driving systems
- Development of a personalized ADAS based on the estimated steering torque and non-parametric driver control models
- Validate traffic MDPs in the realistic 3D simulator
- Model more complex traffic interactions such as intersections, merging, and exiting

Publications

Okamoto, K., and Tsiotras, P., (2016). "A New Hybrid Sensorimotor Driver Model with Model Predictive Control" IEEE Conference on Systems, Man and Cybernetics.

Okamoto, K., and Tsiotras, P., (2018) "A Comparative Study of Data-Driven Human Driver Lateral Control Models," *American Control Conference*, Milwaukee, WI.

You, C., and Tsiotras, P. (2017). "Vehicle Modeling and Parameter Estimation Using Adaptive Limited Memory Joint State UKF" American Control Conference, You, C., and Tsiotras, P., (2016). "Optimal Two Point Visual Driver Model and Controller Development for Driver Assist Systems for Semi-Autonomous Vehicles" American Control Conference, Boston, MA, July 6–8, 2016, pp. 5976–5981.

You, C., Lu, J., and Tsiotras, P. (2017). "Nonlinear Driver Parameter Estimation and Driver Steering Behavior Analysis for ADAS using Field Test Data" IEEE Transactions on Human-Machine Systems, Vol. 47, No. 5, pp. 686–699, October 2017.

You, C., Lu, J., and Tsiotras, P., (2016). "Driver Parameter Estimation Using Joint E/UKF and Dual E/UKF Under Nonlinear State Inequality Constraints" IEEE Conference on Systems, Man and Cybernetics

You C., Lu J., Filev D. and Tsiotras P.,(2018) "Autonomous Planning and Control for Intelligent Vehicles in Traffic", IEEE Transactions on Intelligent Transportation Systems.

You C., Lu J., Filev D. and Tsiotras P., (2018) "Highway Traffic Modeling and Decision Making for Autonomous Vehicle Using Reinforcement Learning", IEEE Intelligent Vehicles Symposium, Changshu, China.

You C., Lu J., Filev D. and Tsiotras P., (2018) "Advanced Planning for Autonomous Vehicles Using Reinforcement Learning and Deep Inverse Reinforcement Learning", Robotics and Autonomous Systems: Special Issue on Semantic Policy and Action Representations for Autonomous Robots.

K. Okamoto, P. Tsiotras, (2019) "Optimal Stochastic Vehicle Path Planning Using Covariance Steering," *IEEE Robotics and Automation Letters*, vol. 4, no. 3, pp. 2276 – 2281.

K. Okamoto, L. Itti, P. Tsiotras, (2019) "Vision-Based Autonomous Path Following Using a Human Driver Control Model with Reliable Input-Feature Value Estimation," *IEEE Transactions on Intelligent Vehicles.* (accepted).

K. Okamoto, P. Tsiotras, (2019) "Data-Driven Human Driver Lateral Control Models for Developing Haptic-Shared Control Advanced Driver Assist Systems," *Robotics & Autonomous Systems*, vol. 114, pp 155 – 171.

K. Okamoto, M. Goldshtein, P. Tsiotras, (2018) "Optimal Covariance Control for Stochastic Systems Under Chance Constraints," *IEEE Control Systems Letters*, vol. 2, no. 2, pp. 266 - 271.

B. Goldfain, P. Drews, C. You, M. Baulic, O. Velev, P. Tsiotras and M. J. Rehg, (2018) "AutoRally: An Open Platform for Aggressive Autonomous Driving", *IEEE Control System Magazine.*

You C., Lu J., Filev D. and Tsiotras P., (2019) "Autonomous Planning and Control for Intelligent Vehicles in Traffic", IEEE Transactions on Intelligent Transportation Systems.

K. Okamoto, P. Tsiotras, (2019) "Input Hard Constrained Optimal Covariance Steering," *IEEE Conference on Decision and Control*, Nice, France (under review).

J. Ridderhof, K. Okamoto, P. Tsiotras, (2019) "Nonlinear Uncertainty Control with Iterative Covariance Steering," *IEEE Conference on Decision and Control*, Nice, France (under review).

Y. Razin, K. Feigh, (2019) "Toward Interactional Trust for Humans and Automation: Extending Interdependence," *IEEE International Conference on Advanced & Trusted Computing*, Leicester, UK.

K. Okamoto, P. Tsiotras, (2019) "Optimal Stochastic Vehicle Path Planning Using Covariance Steering," *IEEE International Conference on Robotics and Automation,* Montreal, Canada.

C. You, J. Lu, D. Filev, P. Tsiotras, (2018) "Highway Traffic Modeling and Decision Making for Autonomous Vehicle Using Reinforcement Learning", IEEE Intelligent Vehicles Symposium, Changshu, China.

K. Okamoto, P. Tsiotras, (2018) "A Comparative Study of Data-Driven Human Driver Lateral Control Models," American Control Conference, Milwaukee, WI.

K. Okamoto, M. Goldshtein, P. Tsiotras, (2018) "Optimal Covariance Control for Stochastic Systems Under Chance Constraints," *IEEE Conference on Decision and Control,* Miami Beach, FL.