TECHNISCHE UNIVERSITÄT WIEN

Intelligent Intersection

FFG Research Project 2020 - 2024

INSTITUT FÜR MECHANIK UND MECHATRONIK
Mechanics & Mechatronics

Research Questions

- How to realize an intelligent intersection system using integrated and flexible communication and control?
- How to collect, disseminate, and exploit available real-time information on observed and predicted road user behavior?
- How to ensure road safety and traffic efficiency while optimizing overall energy consumption?

Intersection Simulations

To enable efficient traffic and vehicle control design via realistic traffic simulations

MULTI-AGENT MODEL ARCHITECTURE

Microscopic simulation of traffic scenarios

- scalable solution for simulation, control and information management
- supports various traffic participant types
- flexible and agile with respect to modeled agents and their future behavior
- control and prediction computations
- co-simulation with other traffic simulators

CARLA SIMULATOR

Hyper-realistic traffic simulator for validation of autonomous driving systems

- multi-body dynamics of masses & chassis
- gear box, clutch, engine, and tire models
- multiple (interacting) vehicles

PTV VISSIM

Microscopic/mesoscopic traffic simulation of

- individual vehicles and pedestrians
- customizable driver models for automated and human-driven vehicles

Integrated functionality provides real-time

- calculation of performance parameters
- interaction with agents and infrastructure during simulation

Wiener Straße/Florianer Straße **- CARLA Simulator**

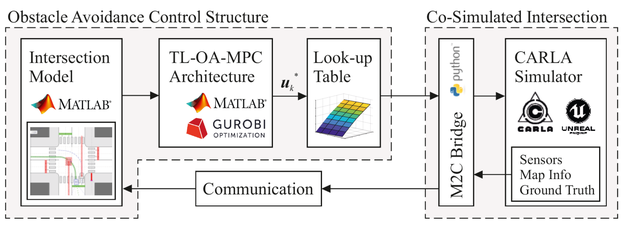
VALIDATION OF CONTROL CONCEPTS

On calibrated intersection simulation models

- *Wienerbergstraße/Triester Straße, Vienna*
- *Webgasse/Gumpendorfer Straße, Vienna*
- *Wiener Straße/Florianer Straße, Linz*

INTERSECTION SELECTION

- urban 4-way intersection with pedestrians and cyclists crossing
- evaluation based on accident-statistics
- real world data from intersections
- evidence based use case definition by focusing on vulnerable road users



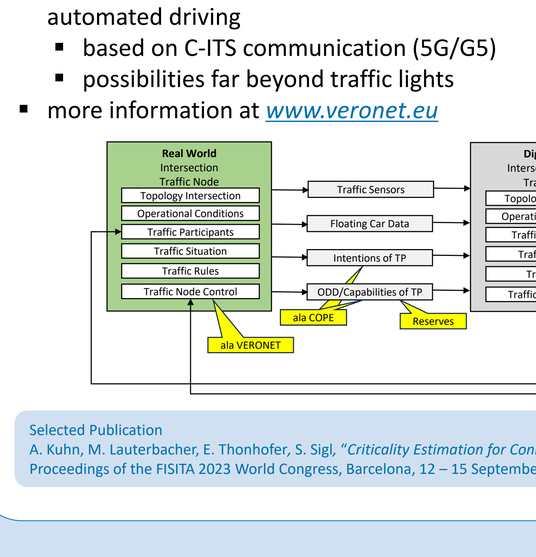
Wienerbergstraße/Triester Straße **- PTV VISSIM**

Selected Publication
A.L. Gratzer, A. Schirrer, S. Jakubek, "*Agile Multi-Agent Model Architecture for Intelligent Intersection Traffic Simulation*",
9th IFAC Symposium on Mechatronic Systems MECHATRONICS 2022, Los Angeles, USA, 2022

Traffic Node Control by Digital Twin

VERONET

Improving intersection performance via scenario adaptive control algorithm



DIGITAL TWIN FOR INTELLIGENT CONTROL

- standardized, bidirectional information flow between physical world and controller
- integration of heterogeneous sources
- up-to-date, reliable information
- OPC UA as technological basis

HOLISTIC CONTROL ARCHITECTURE (VERONET)

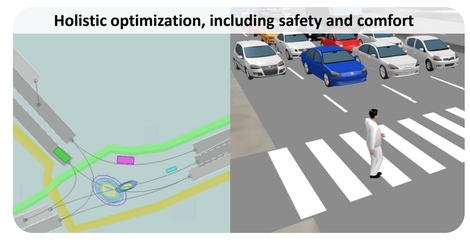
Concept for intelligent and situation-aware, adaptive traffic control

- modular, hierarchical, subsidiary architecture with uniform control modules
- artificial intelligence for situation interpretation, prediction and adaption
- comprehensive scenario management to ensure relevance and representativity
- virtual sensors to provide information about quantities not directly measurable
- virtual traffic control through connected and automated driving
  - based on C-ITS communication (5G/G5)
  - possibilities far beyond traffic lights
- more information at *www.veronet.eu*

BALANCING DIFFERENT CONTROL TARGETS

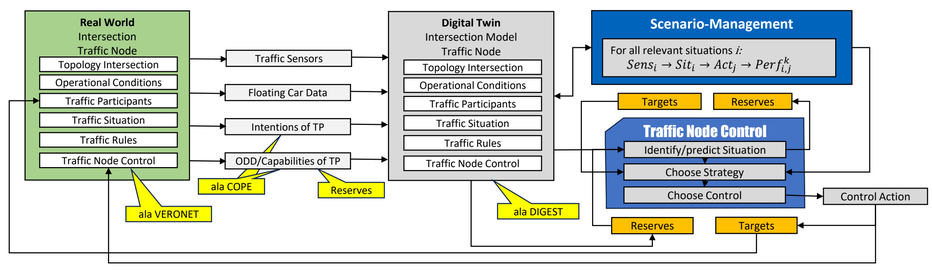
- traffic efficiency (avoid traffic jam, increase capacity, reduce travel times, …)
- safety (reduce collision probability)
- environmental goals (Reduce emissions)
- usability and comfort

Holistic optimization, including safety and comfort



OPTIMAL TRAFFIC CONTROL

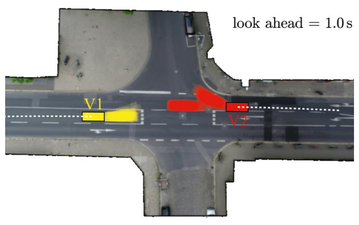
- fine resolution, real time traffic optimization
- considering all traffic participants
- tested in real traffic scenarios

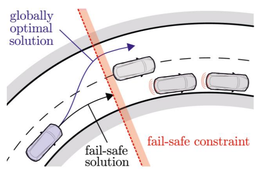


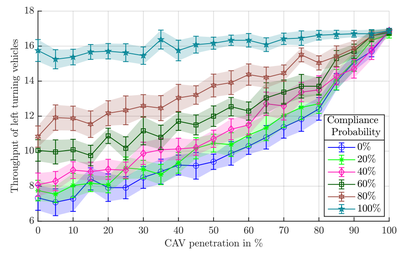
Selected Publication
A. Kuhn, M. Lauterbacher, E. Thonhofer, S. Sigl, "*Criticality Estimation for Connected, Cooperative Collision Avoidance*",
Proceedings of the FISITA 2023 World Congress, Barcelona, 12 – 15 September 2023

Vehicle Control Systems

To enable situation-aware, safe, and efficient automated and human driving







CONNECTED & AUTOMATED VEHICLES (CAVs)

Utilize 5G communication architecture

- motion predictions of road participants
- sensor fusion, collective perception

MODEL PREDICTIVE CONTROL (MPC)

Optimal & versatile vehicle control utilizing

- modeled vehicle dynamics & limitations
- vehicle-to-everything (V2X) communication
- motion predictions of traffic participants

PRECISE OBSTACLE AVOIDANCE (OA)

Flatness-based OA-MPC for CAVs

- globally optimal & collision-free maneuvers
- mixed-integer programming formulation

TWO-LAYER OA-MPC ARCHITECTURE

Coupling of two OA-MPCs to retain real-time computation capability (20Hz)

- MIQP-MPC
  - globally optimal automated driving
- QP-MPC
  - locally optimal driving in real-time

HUMAN DRIVEN VEHICLES (HDVs)

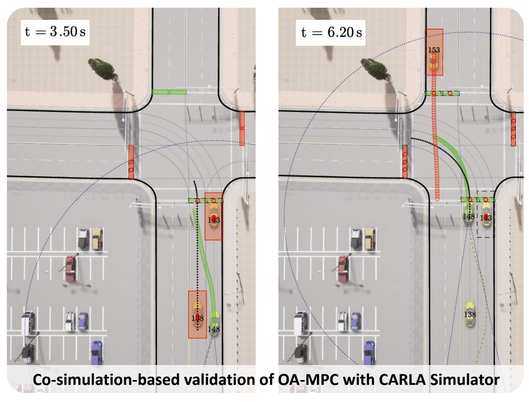
Limited visual-based perception

- reference trajectories cannot be specified remotely (acceleration & steering angle)
- reaction time, perception & driving errors

SOFT INPUTS FOR HDVs

Maneuver recommendations via HMI to increase traffic efficiency, safety & awareness

- lane change, velocity adaption
- warning (based on collective perception)

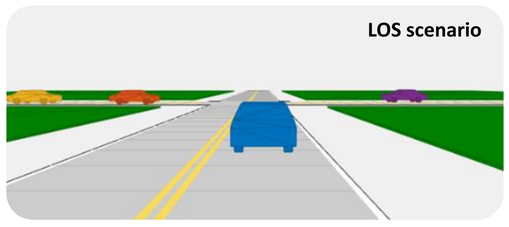


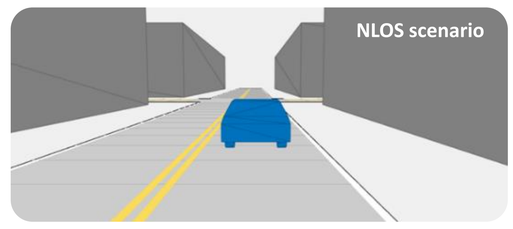
Co-simulation-based validation of OA-MPC with CARLA Simulator

Selected Publication
A.L. Gratzer, M. Broger, A. Schirrer, S. Jakubek, *"Two-Layer MPC Architecture for Efficient Mixed-Integer-Informed Obstacle Avoidance in Real-Time"*,
IEEE Transactions on Intelligent Transportation Systems, submitted & under review

5G New Radio Vehicle-to-X Dependable Connectivity

Smart connected infrastructure for all road users, driven and driverless vehicles





COMMUNICATION ARCHITECTURE

- connect all road users
- low latency dependable connectivity
- 5G NR V2X: 3GPP TR 37.885 Spec
- various urban intersection scenarios

COOPERATIVE PERCEPTION MESSAGING

- On-Board-Units transmit Basic Safety Messages (BSM) periodically
- inter BSM arrival time 30ms
- latency requirement < 30ms
- BSM contains location, speed, and direction of nearby road users
- aims at reducing accidents

COMMUNICATION SCENARIOS

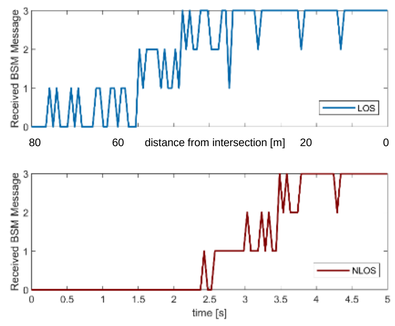
- LOS scenario (Line-of-Sight V2X) no obstacles between vehicles
- NLOS scenario (Non-LOS V2X) reliable transmission requires shorter distance between road users
- urban vehicle speed up to 60 km/h

DEVICES & REQUIRED INFRASTRUCTURE

- Road-Side-Unit at intersection
- all road users with On-Board-Units
- results show successful BSM reception count vs. distance / time

COOPERATIVE PERCEPTION

- vehicles approach the intersection from a distance of 80m
- decreasing propagation loss over time
- BSM dependability improves towards intersection



Selected Publication
F. Pasic, M. Hofer, D. Radovic, H. Groll, S. Caban, T. Zemen, C. Mecklenbräuker, "*Quantifying the Reproducibility of Multi-Band High Speed Wireless Channel Measurements*", 34th Annual International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC), Toronto, Canada, 2023

This work was supported by the Austrian Research Promotion Agency (FFG) via the research project Intelligent Intersection (ICT of the Future, grant 880830).