Automated Transport Systems (ATS)

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This project concerns optimization of the overall transport efficiency performance with focus on connected collaborative self-driving vehicles by taking advantage of new possibilities for efficient communications and computing, accurate position estimation and smart decision systems.

Vision for the Project

Background: Automated transport systems will revolutionize the efficiency of transportation of people and goods. The European Union's goal is to reduce greenhouse gases by 20 percent by 2020, which means the transport efficiency has to be dramatically improved. The focus has been on more and more fuel efficient and intelligent vehicles, but at the same time automated transports need to be connected in real time to surrounding local as well as central systems, to optimize the overall transport performance. For example, road intersections are accident-prone bottlenecks in the traffic system. By developing intelligent algorithms where vehicles exchange information and decide on a safe schedule for each of them passing the intersection one can improve the traffic flow at the same time as safety is increased and fuel is saved. Another example is platooning of vehicles, where safety and fuel economy can be improved, but the distributed speed control must be implemented to guarantee safety when the distance between the vehicles is decreased, at the same time a real-time coordination system is needed to dynamically create, maintain, and dissolve platoons, taking into account historical and real-time information about the state of the infrastructure. A further example is autonomous vehicles connected to transport control and command centers, used in confined areas like harbors or mines. Here the task is to optimize the transport efficiency and reliability while at the same time taking all local and global constraints into account. To summarize, the increase of computational power is enormous both in devices and on a cloud level, and will continue. Fast communications makes it possible to connect vehicles and the infrastructure to provide enormous possibilities for data analytics and real time decision making. These advances make it possible to build even more effective and sustainable solutions for transport of people and goods.

Objective: Our research focus is on connected collaborative self-driving vehicles with supporting infrastructure. Our objective is to develop methodologies and algorithms for such systems along with theory and open source code. In particular we are interested in adaptive algorithms to assure safe, efficient and reliable solutions. The key research problems explained below concern scalability, resilience and safety for heterogonous autonomous transport systems.

Connection to the other WASP Projects: ATS is a strategic application domain project with strong connection to the more thematic WASP projects. In particular to *Localization and Scalability for Distributed Autonomous Systems,* with focus on data analytics, learning, control, and distributed optimization, and to *Integrating Perception, Learning and Verification in Interactive Autonomous Systems,* with focus on perception methods based on fusion of multi-modal sensory information in combination with learning, and formal verification of autonomous systems.

Future Demonstrations: We have Autoliv AB, Scania AB, AB Volvo and Volvo Car Group involved in this project through industrial PhD students. We have the knowledge and experience from ongoing projects in self-driving cars and trucks, and cooperative driving for efficient transport solutions. We now would like to study even more complex scenarios, such as cooperative heterogeneous platoons, smart intersections and connected mobility in urban environments.

Research Challenges

- *Scalability:* The complexity of automated transport systems of many heterogeneous vehicles and humans in urban environments is huge. One idea is to build on results from other kind of networked systems and to use a layered architecture but at the same time be able to handle the time constraints for critical real-time decision making. Local solutions involving a moderate number of vehicles, in for example a platoon, or in a crossing, interact with solutions on system level guiding traffic flow. With more efficient traffic solutions, the interaction between local control and system level increase so that the dynamics at one crossing influence the traffic flow at the neighboring crossings and the overall performance on system level. Hence, algorithms at different levels need to be co-designed, and there must be a scalability feature where solutions at lower level harmonize with higher levels when larger traffic systems are considered. We will develop algorithms and methodologies to handle a large number of coordinated and collaborative vehicles.

- *Resilience*: How do we construct solutions that are safe, secure and can interact with humans, and at the same time very robust to failures? When we start to optimize transport flows, how do we guarantee resilience with be respect to disturbances and failures? Our objective is to develop resilient and robust transport system that maintains an accepted level of performance despite disturbances, including threats of an unexpected and malicious nature. Another question is how should control and communication be co-designed to enable automated transport in urban and highway scenarios? We believe that tailored resource allocation algorithms can make enable better resilience, performance, and robustness. The challenge lies in developing such resource allocation algorithms (both centralized and distributed) in harmony with the control algorithm.
- *Reliability and Latency:* Autonomous vehicles must make decisions in real time based on accurate and valid information. Here accurate position information and reliable communication is required. 5G technologies can hopefully provide such information, but the achievable accuracy, latency, scalability, robustness to disturbances, hardware and signal processing requirements are still unknown. Here we need to develop performance bounds, centralized and distributed positioning methods, and corresponding planning and control algorithms. For example, in intelligent maneuvering and motion control there are several unsolved questions that mainly relate to the formulation of the problem. This is true especially for what objective function to use.
- *Adaptation and Autonomy:* Smart systems must be able to learn and adapt from their new knowledge, its past actions and even mistakes. We envision automated transport systems consisting of learning autonomous vehicles that interact with each other, real-time critical clouds, and exploit their available data and computational capabilities. We wish to understand the basic principles according to which such cloud/edge-assisted multi-agent systems should be designed if they are to learn, adapt and act in uncertain and evolving environments.

Industrial Challenges

Research in automated transport systems, including self-driving vehicles, is pushed by society to extend capacity and at the same time improve safety, efficiency and sustainability. The target for Sweden is to have a vehicle fleet that is independent of fossil fuels in 2030, and intelligent transport systems and services is one important way to achieve this objective. The current industrial challenges involves self-driving vehicles, but also other radical new ways to improve mobility of people and transport of goods. Enablers are new technologies for e.g. computing and communication leading to safer, more efficient and sustainable transport solutions. Future cooperative automated transportation solutions have to take diverse requirement such as Safety, Heterogeneity and Complexity on a System Level into account in a structured way. Companies and transport organizations are very active in demonstrating new transport solutions based on self-driving vehicles and ICT. These mobility demonstrators form an excellent base for collaboration between industry and academy to address these system challenges.

Sub-projects

Control of Autonomous Vehicles in Complex Traffic with Safety Constraints

Johan Karlsson (academic PhD student), Chalmers

This PhD project concerns development of control algorithms for safe and energy efficient path planning and decision taking in autonomous driving. This will be done with the use of model-based control techniques that incorporate predictive information. The project will focus on addressing this tradeoff by looking beyond the standard MPC techniques of linearization. The project will heavily rely on applied non-linear programming and direct and indirect optimal control.

Communication and Positioning for Automated Transport

Mohammad Ali Nazari (academic PhD student), Chalmers

This PhD project will consider wireless communication systems in the context of cooperative driving. Currently, communication between cars is based on 802.11p, which can support limited situational awareness (by broadcasting position and velocity information). The long-term goal is to harness 5G wireless signals to provide cooperative situational awareness by sharing complete maps, and cooperative control, through distributed solving of optimal control problems.

Interacting Motion Control
Pavel Anistratov (academic PhD student), Linköping University
This PhD project will consider interacting motion control by means of trajectory planning and optimization. It will take maneuvering capabilities of the vehicle, other vehicles, and traffic situation into account in order to formulate objective functions, constraints and choose vehicle models.

Link Modelling for Cooperative Transport Solutions
Christian Nelson (academic PhD student), Lund University
This PhD projects concerns link modelling for cooperative transport solutions, where we put emphasis on safety critical aspects such as latency, relative positioning, reliability and their interaction with the control system for collaborative transport solutions.

Coordinated Learning and Control of Vehicles
Linnea Persson (academic PhD student), KTH
This PhD projects concerns smart multi-agent systems and the corresponding data processing algorithms to provide agents with a an accurate description of their environment and its evolution, as well as optimization and control algorithms enabling agents to select and update in real-time their actions.

Automated Vehicle Control over Mobile Networks
Dirk van Dooren (academic PhD student), KTH
This PhD projects concerns real-time control of autonomous vehicles over mobile networks and in particular handover of control tasks without sacrificing safety or performance of the vehicular system. Demonstrations on control of formations will be done in the Smart Mobility Lab and in real-world experiments are planned in connection to the Connected Mobility Arena.

Motion Planning for Autonomous Driving within Urban Environments
Rui Oliveira (Industrial PhD student), Scania and KTH
This industrial PhD project concerns motion planning for safe autonomous driving within urban environments. The motion planner will receive instructions from a global mission planner. The project will investigate local on-board refinements and adjustment according to contingent factors, such as traffic conditions, speed, time and fuel efficiency of the plan based on vehicle sensory information and data from the roadside infrastructure

Driving Automation in Complex Environments - Volvo
Tommy Tram (Industrial PhD student), Volvo Car Group and Chalmers
The goal in this industrial PhD project is to consider decision making and path planning in complex traffic situations including crossings and roundabouts. Without direct communication between vehicles, the behavior of the surrounding traffic needs to be treated as uncertain and to be incorporated control the algorithms.

Driving Automation in Complex Environments – Autoliv
Ivo Batkovic (Industrial PhD student), Autoliv AB and Chalmers
The goal in this industrial PhD project is to consider decision making and path planning in complex traffic situations including crossings and roundabouts. The research focus is to investigate the sensors' influence on the algorithms so that the relation of the sensor equipment on the driving performance is better understood.

Tactical Decision-Making in Dynamic Uncertain Traffic Situations
Carl-Johan Hoe (Industrial PhD Student), AB Volvo and Chalmers
This PhD project targets the problem of making autonomous, tactical decisions in uncertain traffic situations, balancing safety and efficiency. The project will focus on a time horizon of around 0.5 to 20s. Thus, it will neither involve more long-term route planning, nor actuator coordination which is carried out on a faster time scale.