RUHR-UNIVERSITÄT BOCHUM
Institute of Automation and Computer Control
Prof. Dr.-Ing. Jan Lunze

Universitätsstr. 150 Phone +49-(0)234 32-28071
D-44805 Bochum Fax +49-(0)234 32-14101

Cooperative Control of Networked Vehicles

Alexander Schwab
schwab@atp.rub.de

1 Networked vehicles

Autonomous driving is a highly discussed topic and is expected to improve traffic efficiency and safety. There are commercial driver assistance systems available that maintain a safety distance to the predecessor and perform autonomous lane changes. However, a merging vehicle has to wait for a sufficiently large gap on the target lane before it can change the lane.

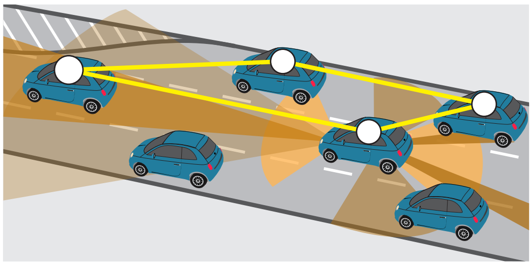

Fig. 1: Cooperative vehicles

In the future, all vehicles will be equipped with communication systems which enable them to cooperate with each other. Figure 1 shows a set of cooperative vehicles which are coupled in two ways [2]:

- **Cognition:** The vehicles are equipped with sensors to detect the environment and other vehicles.
- **Communication:** The local vehicle controllers can communicate with each other to perform cooperative manoeuvres if necessary.

The communication system is only used when a cooperation of multiple vehicles is mandatory to perform a specific manoeuvre, for example, merging before a lane reduction when there is no sufficiently large gap on the target lane. The vehicles on the target lane then receive a request from the merging vehicle and generate a gap cooperatively for the merging vehicle to steer in.

A set of networked vehicles can be modelled as a multi-agent system as illustrated in Fig. 2, which consists of N physically uncoupled plants P_i that are controlled by local controllers C_i. These controlled subsystems are able to communicate with each other via a given communication network to exchange control variables and set-points or possibly model information in a more general framework.

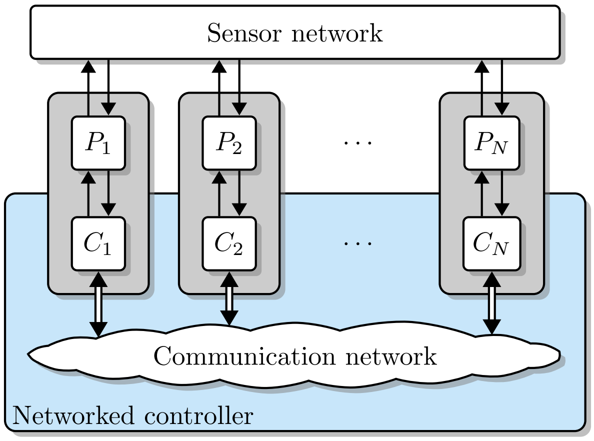

Fig. 2: Multi-agent system

2 Project aim

The aim of this project is to find methods for the design of the local controllers and of the communication structure such that the overall system possesses a desired behaviour, which leads to the following question:

How can requirements on the overall system be translated into requirements on the controlled subsystems and the communication structure?

The developed methods are applied on different traffic scenarios, for example lane reductions, intersection management or swarms of vehicles from a more abstract perspective.

3 Control of a swarm of vehicles

A set of vehicles coupled by sensors and communication links on an open plane as illustrated in Fig. 3 is called a swarm of vehicles. The vehicles have common aims as collision avoidance and individual aims as a specific destination. On their trajectories, the vehicles have to establish new communication links between neighbouring vehicles while some old connections may be cut off. Consequently, the overall dynamic behaviour of a networked system depends on both the properties of the controlled subsystems and the coupling structure.

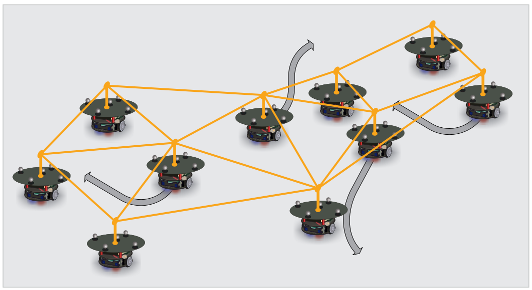

Fig. 3: Swarm of vehicles

4 Example: Vehicle platooning

Consider a set of N identical vehicles driving in a straight line equipped with a distance controller and a communication system to exchange information. The velocity of each vehicle is denoted by $v_i(t)$ and the position by $s_i(t)$. The inter-vehicle distance of two consecutive vehicles is given by $d_i(t) = s_{i-1}(t) - s_i(t)$. The controllers should be designed such that the following requirements are met:

(R1) **Asymptotic synchronisation:** In a steady state, all vehicles should travel with the same constant reference velocity $v_0(t) = \bar{v}$

$$\lim_{t \to \infty} |v_i(t) - v_0(t)| = 0, \quad i = 1, 2, \ldots, N.$$

(R2) **Asymptotic time-headway spacing:** For constant reference velocity $v_0(t) = \bar{v}$, the distances should satisfy the requirement

$$\lim_{t \to \infty} |d_i(t) - d_0 - \beta v_i(t)| = 0, \quad i = 1, 2, \ldots, N$$

with β denoting the time-headway coefficient.

(R3) **Continuous progression:** There should be no situation in which a vehicle moves backwards, i. e.

$$v_i(t) \geq 0, \quad t > 0, \quad i = 1, 2, \ldots, N.$$

(R4) **Collision avoidance:** All vehicles should comply with a minimum distance d_0

$$d_i(t) \geq d_0, \quad t > 0, \quad i = 1, 2, \ldots, N.$$

In order to satisfy requirements (R3) and (R4), the vehicles have to possess externally positive dynamics, i. e. the closed-loop impulse response has to be nonnegative

$$\bar{g}(t) \geq 0, \quad t \geq 0,$$

which guarantees collision avoidance [1]. In [4], it has been shown how to achieve the desired closed-loop properties and an extension to merge multiple platoons before lane reductions was discussed in [3] using the cooperative trajectory tracking controller presented in [5].

5 Experimental evaluation

The experimental plant SAMS (***S****ynchronisation of* ***A****utonomous* ***M****obile* ***S****ystems*) is used at the Institute of Automation and Computer Control at the Ruhr-University Bochum to test all developed methods for the coordination of multi-agent systems (Fig. 4).

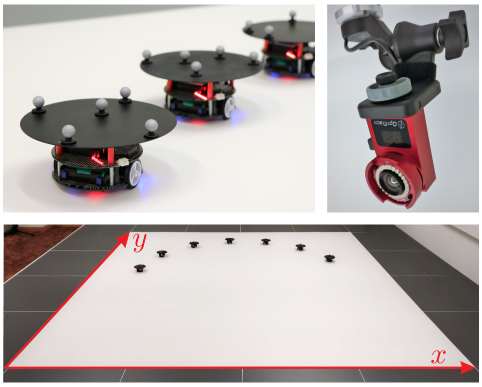

Fig. 4: SAMS with the robots (top left), camera (top right) and the driving surface (bottom)

Figure 5 shows an experimental evaluation of the merging concept proposed in [3] that allows for combining multiple platoons to pass a lane reduction. The distance between robots on the main lane in the transition region is increased so that a gap is generated which is large enough for an additional robot from the merging lane to steer in.

References

[1] J. Lunze. Adaptive cruise control with guaranteed collision avoidance. *IEEE Trans. on Int. Transp. Systems*, 20(5), 2018.

[2] J. Lunze. *Networked Control of Multi-Agent Systems*. Bookmundo Direct. ISBN 9789463867139, 2019.

[3] A. Schwab and J. Lunze. Cooperative vehicle merging with guaranteed collision avoidance. In *IFAC Workshop on Contr. of Transp. Systems*, 2019.

[4] A. Schwab and J. Lunze. Design of adaptive cruise controllers for externally positive vehicles. In *IFAC World Congress*, 2020.

[5] A. Schwab, K. Schenk, and J. Lunze. Networked vehicle merging by cooperative tracking control. In *IFAC Workshop on Distributed Estimation and Contr. in Networked Systems*, 2019.

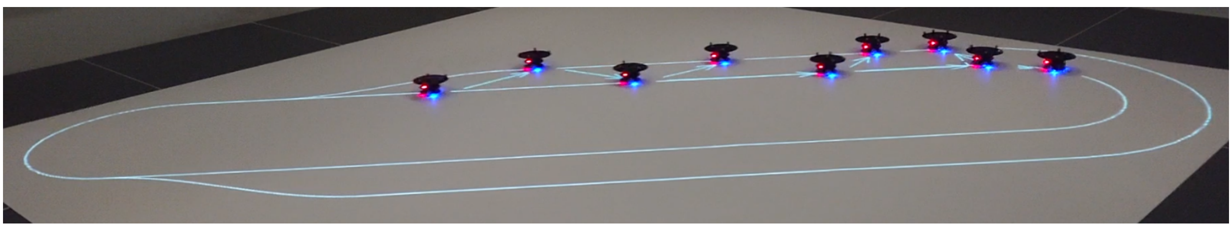

Fig. 5: Experimental evaluation of merging robots