Why is autonomous localisation required in lateral cooperative control?

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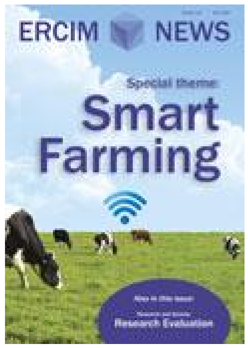

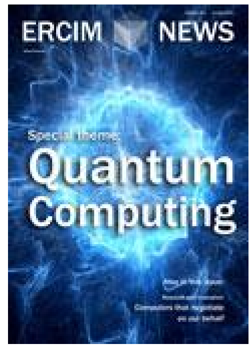

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by Tom van der Sande (Eindhoven University of Technology), Jeroen Ploeg (TNO) and Henk Nijmeijer (Eindhoven University of Technology)

What is the link between cooperative automated vehicles and autonomous vehicles? At the Eindhoven University of Technology, we recently started the i-CAVE (integrated cooperative automated vehicles, STW14893) project, focusing on the development of dual-mode operation of cooperative automated and autonomous vehicles, which will provide an answer to this question. Here we discuss the state of the art of cooperative automated and autonomous vehicles using the guidelines as provided by the Society of Automotive Engineers (SAE) and show that contemporary systems are far from being fully autonomous.

Although we have been driving cars for more than a century, human error remains the primary cause of accidents. One way of solving this problem is to automate the task of driving. This can be done on five levels, as specified in SAE-J3016. At level 1, the vehicle automates the longitudinal or the lateral motion, whereas the driver is always required to pay attention. Level 2 has similar characteristics, except that both longitudinal and lateral motion are automated. With level 3, the automation system will monitor the environment and warn the driver in case of danger, but the driver is used as fall-back. Beyond level 3, the system performs fall-back functionality.

The question is how to maintain the driver at a sufficient awareness level to perform the required monitoring and fall-back task at lower automation levels: level 3, in particular, might give a false sense of safety. Consequently, level 3 automation should only be done within a closed perimeter, designed exclusively for automated driving and careful driver instruction.

An example of a commercially available system functioning at level 1 is adaptive cruise control (ACC). We show that this system has only limited performance when encountering busy traffic [1] because large errors of the desired distance might occur. By incorporating wireless communication, referred to as cooperative adaptive cruise control (CACC), this issue can be solved. Vehicles equipped with CACC (shown in figure) communicate desired acceleration, in contrast to ACC, which only uses the relative position and velocity. In an ideal situation, with no communication delay and identical vehicles, the feedback system of the ACC-controller is now obsolete. As such, CACC is a typical example of cooperative automation, characterised by relying on information obtained via wireless communication.

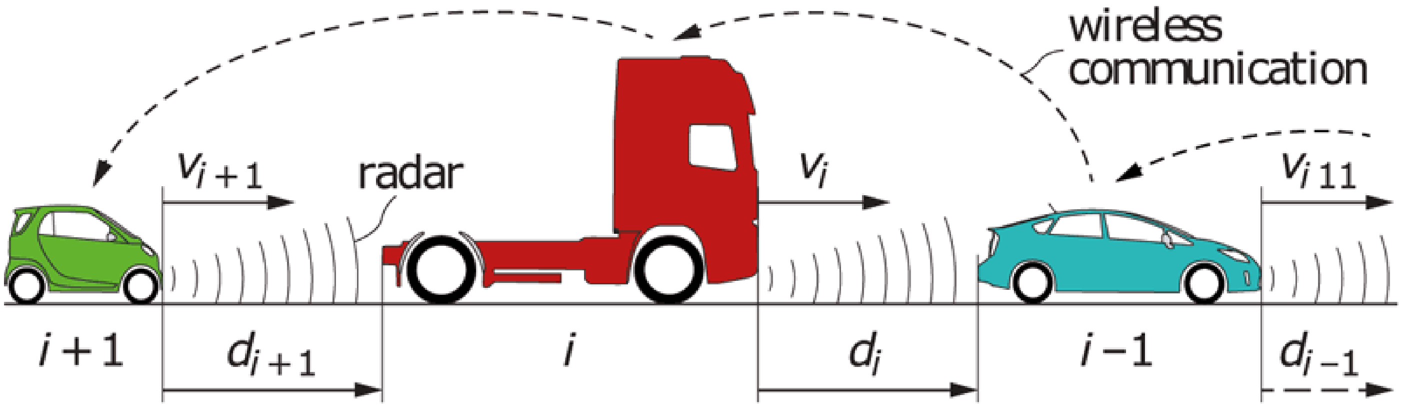

Figure 1: A homogeneous vehicle platoon. Our research shows that contemporary systems are still far from being fully autonomous, as they will benefit from information that can only be obtained through communication. Picture: J.PLoeg [1].

The assumption that in a perfect world no additional information is required vanishes when considering lateral cooperative manoeuvring. To visualise this, consider a vehicle that is moving on a plane, giving it a longitudinal, lateral and yaw degree-of-freedom. For it to move in a lateral direction, it should have a longitudinal velocity and yaw-rate, indicating the coupled and non-linear dynamics and the resulting control problem. As long as the vehicle is moving, we show that input-output linearization by state-feedback decouples these dynamics. Consequently, a vehicle-following controller is developed by using PD-control [2]. This gives rise to a particular problem: corner cutting. In case of lateral vehicle automation, it may cause the follower vehicle to leave its lane. Thus, the vehicle can no longer rely solely on the information received from the preceding vehicle, but it needs to have self-awareness about its position and surroundings. This bridges the gap between cooperative and autonomous vehicles [3].

The analysis above shows that for combined longitudinal and lateral CACC, the vehicle needs to be aware of its own location with respect to infrastructure as the default controller promotes corner cutting. To this end, on board sensors such as radar, scanning lasers or cameras are employed.

In conclusion it is worth asking whether we can design a successful automated vehicle without communication. Obviously full autonomy must be a fall-back mechanism of automation in combination with communication, however to be successful as an individual vehicle, do we need to know more about our environment than our on board sensors tell us? Classical control theory teaches us there is a large benefit in using information in the control system that can only be obtained through communication.

Link:
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[2] A. Bayuwindra, Ø. Aakre, J. Ploeg, H. Nijmeijer: “Combined lateral and longitudinal CACC for a unicycle-type platoon”, 2016 IEEE Intelligent Vehicles Symposium (IV).
[3] T. van der Sande, H. Nijmeijer: “From cooperative to autonomous vehicles”: Springer LNCS, 2017. DOI: 10.1007/978-3-319-55372-6

Please contact:
Tom van der Sande
TU/e, The Netherlands
+31402475730
t.p.j.v.d.sande@tue.nl (mailto:t.p.j.v.d.sande@tue.nl)

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