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Citation for published version (APA):
van den Broek, T. H. A., Ploeg, J., & Netten, B. D. (2011). Advisory and autonomous coopeerative driving systems. In *Proceedings of the IEEE International Conference on Consumer Electronics (ICCE 2011), 9-12 January 2011, Las Vegas, USA* https://doi.org/10.1109/ICCE.2011.5722582

DOI:
10.1109/ICCE.2011.5722582

Document status and date:
Published: 01/01/2011

Document Version:
Publisher’s PDF, also known as Version of Record (includes final page, issue and volume numbers)

Please check the document version of this publication:

• A submitted manuscript is the version of the article upon submission and before peer-review. There can be important differences between the submitted version and the official published version of record. People interested in the research are advised to contact the author for the final version of the publication, or visit the DOI to the publisher's website.
• The final author version and the galley proof are versions of the publication after peer review.
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Advisory and Autonomous Cooperative Driving Systems

Thijs H. A. van den Broek, Jeroen Ploeg, and Bart D. Netten

Abstract — *In this paper, the traffic efficiency of an advisory cooperative driving system, Advisory Acceleration Control is examined and compared to the efficiency of an autonomous cooperative driving system, Cooperative Adaptive Cruise Control. The algorithms and implementation thereof are explained. The results of both systems are presented and discussed*[1].

Index Terms — Advisory systems, autonomous systems, cooperative driving technology, vehicle-vehicle communication.

I. INTRODUCTION

Congestion is a major societal problem in the Netherlands, considering a daily average total traffic jam length of over 200 km and peaks to well over 500 km during rush hours, whereas the country only measures 150 x 300 km [1].

Traffic jams will obviously occur when the physical road capacity is not sufficiently high compared to the incoming traffic demand, for instance due to road works or accidents. Another major reason for traffic jams are so-called *ghost traffic jams*. When drivers follow at relative close distance, common during rush hours, a mild braking action of a single vehicle may lead to a disturbance that amplifies in upstream direction, ultimately bringing the upstream vehicles to a full stop, without an apparent cause such as a road works [2]. The underlying mechanism of ghost traffic jams is formalized by the notion of *string stability*, which states that a string of vehicles is stable when downstream disturbances are attenuated in upstream direction. As such, a string stable system contributes to a smooth traffic flow, which in turn leads to an efficient road use, less congestion and also to increased fuel efficiency [3].

In [4] a driver assistance system aiming at increased string stability and traffic flow is designed and validated, and some first results are presented[2]. Here, the comparison is made with respect to traffic efficiency between the advisory acceleration controller (AAC) of [4] and the autonomous cooperative adaptive cruise controller (CACC) of [5].

II. ALGORITHMS

The AAC algorithm of [4] is based on the CACC algorithm of [5]. The main difference is the actuation of the vehicle. The AAC actuation is performed by means of a driver in the loop, and the CACC actuation is autonomous. Obviously, the actuator time delay of the advisory system is larger and the actuator accuracy is less accurate. A brake reaction time of 0.7 to 1.1 seconds is determined in [6], while a vehicle, e.g. Citroen C4, has a time delay of only 0.2 seconds [5].

Assume a string of vehicles with the control structures that are schematically shown in Figure 1.

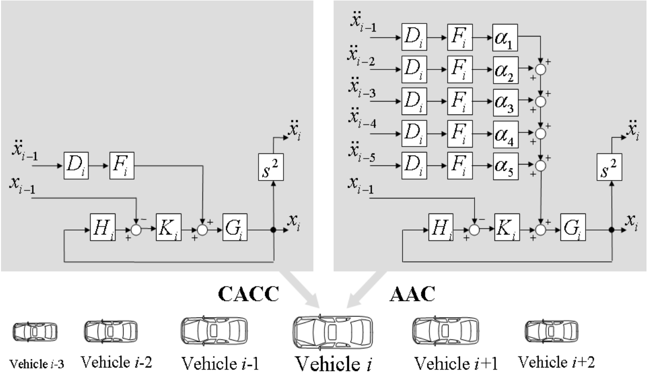

Fig. 1. Control structure of the i^{th}-CACC and i^{th} -AAC vehicle.

In Figure 1 the communication delay D_i, feedforward controller F_i, the spacing policy H_i, feedback controller K_i and vehicle model G_i of the i^{th} vehicle are shown. The predecessor of the i^{th} vehicle is defined as the i-1th vehicle. The mathematical models are given in [5].

In order to advise the driver as soon as possible for disturbances within a string of vehicles the AAC controller takes the acceleration into account of 5 predecessors. In the upper right part of Figure 1 the control structure of the i^{th} AAC vehicle is shown. The parameters D_i, F_i, H_i, K_i, and G_i are similar to the CACC controller. The weighting parameters α_1 till α_5 are chosen as 5/12, 3/12, 2/12, 1/12, and 1/12, respectively. In other words, the acceleration of the direct predecessor (i-1) is most important and the acceleration of the fifth predecessor (i-5) is least important.

Next, the weak string stability of the sixth vehicle with CACC and AAC is defined for different actuator time delays. The string stability criterion concerns the amplification of signals, e.g. accelerations, in upstream direction. Here, string stability in the frequency domain is defined as the ratio between the output X of the i^{th} vehicle and the first vehicle as

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[1] This work is supported in part by the Strategic Platform for Intelligent Traffic Systems (SPITS) project of SenterNovem, https://spits-project.com/.

[2] More detailed results are shown in http://www.A270demo.nl

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978-1-4244-8712-7/11/$26.00©2011 IEEE

$$\left|SS_i(j\omega)\right| = \left|\frac{X_i(j\omega)}{X_1(j\omega)}\right| \le 1 . \tag{1}$$

In Figure 2 the string stability of the sixth vehicle, with a time headway of 1.2 seconds, is shown with different actuator time delays for the AAC and CACC controller. It becomes clear that for an actuator time delay larger than 0.4 s the AAC controller is more string stable for different frequencies. This validates the choice to use the AAC controller for a driver-in-the-loop implementation.

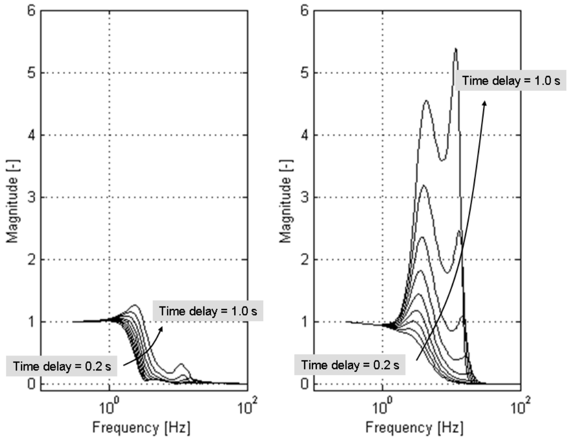

Fig. 2. The weak string stability of the sixth AAC (left) and CACC (right) vehicle.

III. IMPLEMENTATION

The CACC controller is experimentally validated in [5]. Hence, this controller is suitable to serve as a reference case for the AAC controller.

The implementation of the AAC controller is explained in detail in [4]. The human machine interface (HMI) is displayed on common portable navigation devices: see right plot of Figure 3. An experiment, with lead vehicle and both groups of vehicles, is shown in the left plot of Figure 3.

Fig. 3. The implementation of the AAC controller in experiments.

IV. TRAFFIC EFFICIENCY

In [4] the AAC vehicles are compared to the reference group of vehicles. In Figure 4 the comparison between the reference vehicles, AAC vehicles and CACC vehicles is made for all experiments, where the CACC vehicles are simulated ones. The linear relationship between average speed and average density of the CACC vehicles is directly related to the constant time headway of 1.2 s. In [4] the AAC vehicles drive with time headway that is *about* 1.2 s. Sometimes the time headway is shorter, resulting in a higher density compared to the CACC vehicles, and sometimes the time headway is larger, resulting in a lower density compared to the CACC vehicles. The fluctuations of the density of the AAC vehicles are mainly due to the inflow and outflow of the shockwaves within the string of vehicles.

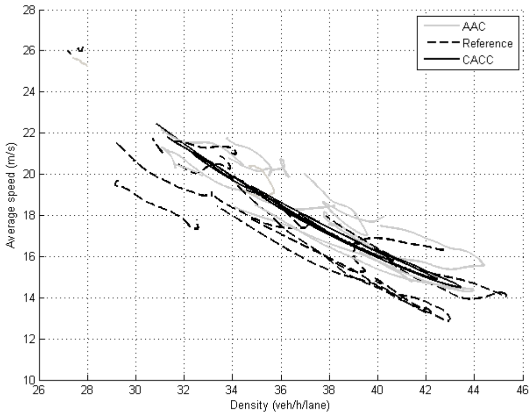

Fig. 4. The average density versus average speed for the reference vehicles, AAC vehicles and CACC vehicles.

V. CONCLUSION

AAC is a good remedy to increase the density at different velocities, i.e. improve the traffic flow, for shockwaves at highways. Although it is an advisory system, drivers are able to perform better than the reference vehicles. For these specific experiments, where both CACC and AAC had the same time headway of 1.2 seconds, the advantage of autonomous vehicles (CACC) compared to AAC, with respect to traffic efficiency, is limited.

Note that autonomous vehicles are a better solution to further increase the traffic flow. First, the time headway can be decreased without affecting the string stability. A smaller time headway results in an increased density at similar velocities. Second, it is very demanding for the drivers with the AAC system to act accurately to the advisory system. With autonomous vehicles the driver comfort is increased.

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