CARTALK 2000: DEVELOPMENT OF A CO-OPERATIVE ADAS BASED ON VEHICLE-TO-VEHICLE COMMUNICATION

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SUMMARY

Advanced Driver Assistance Systems (ADAS) benefit from using vehicle-to-vehicle communication. In the 5th framework EC project CarTALK2000 co-operative ADAS are designed, tested and evaluated with respect to increasing traffic safety, efficiency and driving comfort. Communication based longitudinal control (CBLC) systems extend the driver’s horizon and supplement state-of-the-art ACC and Stop&Go systems. Research in communication and positioning technology is used to design longitudinal co-operative vehicle control systems by TNO and DaimlerChrysler AG. Conditioned evaluation tests of the CBLC systems give an impression of the benefits of co-operative driving.

INTRODUCTION

The modern society's increasing mobility is placing a growing demand on traffic safety and efficiency. Recent technological developments in the area of driver support systems, commonly known as Advanced Driver Assistance Systems (ADAS), are very promising for enhancing traffic safety. Adaptive Cruise Control (ACC) is an example of such a system that is already commercially available. Although ACC primarily aims at the improvement of driving comfort, it has the potential to increase traffic safety as well by automatically keeping a preset distance to the vehicle in front. A common characteristic of most ADAS, whether they automate (part of) the driver’s tasks or 'just' give an instructive message, is the inclusion of on-board sensors to scan the direct vicinity of the vehicle. The range covered by these sensors however is limited by nature, which restricts the anticipative capabilities of the system. Vehicle-to-vehicle communication combined with advanced positioning technology solves this problem. It is considered the key for significantly boosting progress in the development path of ADAS. Vehicle-to-vehicle communication enables any ADAS to use data collected by other vehicles, thus largely extending the range of traffic information. A direct communication link between vehicles furthermore offers time-critical and robust data exchange, which is a prerequisite for safety related applications. As a result preview information is gained, al-

lowing the driver or an automated system to perform anticipatory actions, typically beyond the direct predecessor. Co-operative driving based on this principle has a good perspective to improve the overall traffic safety, supply more driving comfort and optimize traffic flows.
In line with this motivation the key objective of the EC 5th framework project CarTALK2000 is to design, test and evaluate co-operative driver assistance systems based upon vehicle-to-vehicle communication in order to improve the overall safety of the traffic participants. Furthermore CarTALK addresses driving comfort and the efficiency of traffic flows. In the project three application clusters have been identified: Information and Warning Functions (IWF), Communication-based Longitudinal Control (CBLC) and Co-operative Assistance Systems (CODA) [3]. This paper focuses on applications within the CBLC cluster [1], describing development and implementation issues of the CarTALK system and exploring functional and technological progress. In parallel an evaluation methodology based on traffic simulations and socio-economic impact analysis is described in [2].
The following research questions are addressed:

- Advanced positioning technology: what is the feasibility of a combined Extended Kalman Filtering (EKF) and vehicle-to-vehicle communication approach for implementation in a longitudinal control system?
- What are the technological and functional benefits of this longitudinal control system for CBLC traffic scenarios?

The current status of CarTALK work is described first, distinguishing application development, the vehicle-to-vehicle communication system and hardware architecture. Next, the development state of applications will be described in more detail. The focus is on positioning technology and co-operative control from both a TNO and DaimlerChrysler perspective. To evaluate the TNO control system it is implemented in a series of demonstrator vehicles that are not yet fully equipped according to the final CarTALK specifications. Subsequently results of this evaluation for a Stop&Go scenario are described and finally conclusions and an outlook of further work will be formulated.

CURRENT STATUS OF CARTALK WORK

Technological challenges of the CarTALK project are the development of applications according to the three clusters IWF, CBLC, CODA, the evaluation of these applications in co-operating demonstrator vehicles of different partners and the development of the ad-hoc, decentralized communication system. This section describes results up to now and expected results regarding application development in the CBLC cluster, the communication system and architecture of the vehicle test platforms.

Application development

Better longitudinal traffic control is beneficial for safety, usage of available road capacity and driving comfort. The risk on rear-end crashes can be reduced and consequently the amount of casualties and injuries will be lower. CBLC can reduce the amount of incidents on highways that cause congestion and it can stabilize traffic flows due to the anticipative and feed-forward character of co-operative driving. Starting with ACC functionality, a vehicle-to-vehicle communication system can further increase safety and driving comfort by providing an extension of the radar-like observation horizon. For this reason, in CarTALK the project partners TNO and DaimlerChrysler are exploring the merits of communication based longitudinal control for co-operative Early Brake Warning (EBW) [1] and Stop&Go functionality.

The main objective of DaimlerChrysler's assisting systems department is to enhance the ACC technology by providing additional sensors that complement the sensor information gathered from the ACC radar sensor. The radar sensor that is already accomplished in ACC systems fulfills the basic requirements of advanced cruise control systems by providing reliable and accurate data. The overall system can be classified as a comfort system, as the control is handed over to the driver when e.g. certain thresholds for the expected acceleration or deceleration are exceeded. Although the ACC system facilitates safe and comfortable driving on motorways to a certain extend, it lacks human like, anticipative driving behavior. A system which is able to detect all relevant vehicles in front, namely the vehicles in front of the leading vehicle and the vehicles on neighboring lanes, could manage a more natural behavior regarding its control strategy which could be adapted to the overall traffic flow. Most sensors require line of sight, so that is merely possible to adapt the control strategy to vehicles in the local environment. Communication sensors together with multi-hop routing strategies can overcome this shortcoming. As a first step, one of the CarTALK scenarios investigates the 'transparent front vehicle', where the control strategy is adjusted to the vehicle in front of the leading vehicle in the own lane as indicated in figure 1.

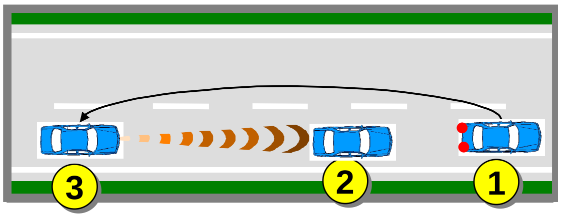

Figure 1. Traffic scenario for longitudinal control illustrating the merits of vehicle-to-vehicle communication for current ACC systems

Co-operative Stop&Go is another challenging type of longitudinal control to be reached with vehicle-to-vehicle communication. A Stop&Go system controls vehicle speed and headway during both congested traffic with many speed changes and high speed cruising [6]. It is considered an extension of ACC since it provides control of the distance or time to the predecessor at each distance or speed, including low speeds. In a more advanced version of Stop&Go based on co-operative driving, vehicles in a cluster are capable of automatically following each other at an appropriate distance at a wide speed range. Co-operative driving by vehicle-to-vehicle communication optimizes deceleration (Stop) behavior, similar to the Early Brake Warning functionality [1], and acceleration (Go) behavior. This can significantly reduce driver workloads, enhance traffic safety and optimize traffic flow.

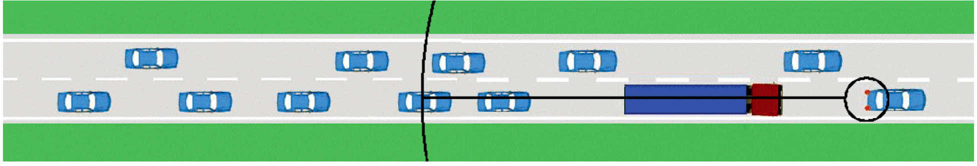

Figure 2. Traffic scenario for communication based longitudinal control in both congested traffic and during high speed cruising

Vehicle-to-vehicle communication system

The inter-vehicle communication system for CarTALK applications is based on a self-organizing, mobile ad-hoc network with neither the need of preinstalled infrastructure nor the involvement of network operators. The communication architecture extends the common use of a three-layer architecture (physical-, link-, and application layer) for real-time systems by a network layer to enable multi-hop, spatial aware, position-based routing [9]. For the planned inter-vehicle communication system a physical- and link-layer based on an UMTS terrestrial radio access network (UTRA) technology is designed [10]. The system is operating in time division duplex (TDD) mode and is adapted for the decentralized ad-hoc mode without a base station. In Europe the frequency band between 2.01 and 2.02 GHz is reserved for the use by UTRA-TDD.

For the support of the demo applications, an 802.11b based WLAN communication system will be implemented in accordance with the proposed architecture. The WLAN demo communication system will use standard 802.11b PC cards operated under Linux. Physical- and link layer are implemented by the card's hardware/firmware and the drivers of the Linux operating system. The network layer functionality is provided by a software implementation using additional control services, like a neighbor service (for the discovery of neighboring stations) or a location service (to get the current geographical position of a station). This information is needed for the position based forwarding and addressing of the routing approach. At this stage of the project the geographical data for the spatially aware routing service is obtained by advanced positioning algorithms for each vehicle. This data can directly be coupled to geographic information from digital maps that are used for e.g. route navigation. The data is part of a common message format for all cars that will communicate in the ad-hoc vehicle network.

Reference architecture

A reference architecture has been defined for the demonstrator vehicles of the project partners DaimlerChrysler, CRF and TNO. The definition of such a reference architecture based on an open standard will be more successful for upcoming standardization than a mandatory implementation. In line with this philosophy the CarTALK reference architecture allows different real-time vehicle implementations while guaranteeing interoperability on the communication and application level.

The development of the reference architecture starts with the definition of a functional architecture, based on a functional analysis of the three scenario clusters. This functional architecture consists of five elements: localization, communication, telematics, vehicle signals and on-board processing, as depicted in figure 3.

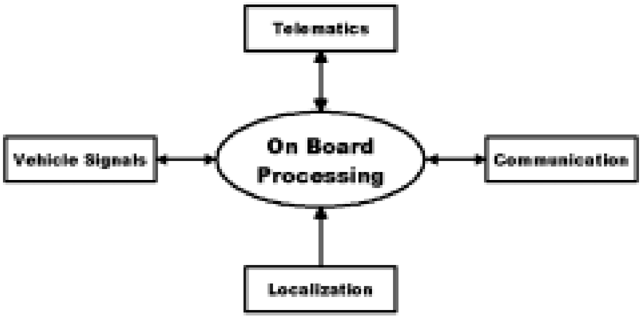

Figure 3. Functional architecture for CarTALK vehicles

The centrally placed 'On-board Processing' unit runs the algorithms of the CarTALK applications. The 'Localization' unit is used for generating the position data necessary for supporting the CarTALK applications. Apart from that it is used for the spatially aware routing approach as part of the communication system. The 'Communication' unit deals with receiving data from and transmitting data to other vehicles. The 'Telematics' unit supports different telematics functions, including the Human Machine Interface (HMI). The ‘Vehicle Signals’ unit gathers OEM proprietary data and data from additional in-vehicle sensors.

Subsequently the CarTALK reference architecture has been defined in line with the architecture proposed by the AMI-C (Automotive Multimedia Interface Collaboration) consortium. This architecture accommodates the usage of a wide variety of computer based electronic devices in vehicles. It consists of an interface to vehicle specific (OEM) information, one or more open networks to which computer devices can be added and gateways between these networks. The CarTALK reference architecture, as illustrated in figure 4, extends the OEM gateway concept of AMI-C with an inter-vehicle communication gateway [11]. The telematics and vehicle control parts are placed in the ‘open’ environment equivalent to AMI-C.

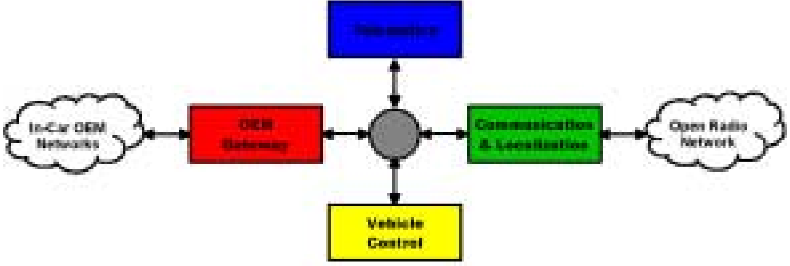

Figure 4. CarTALK reference architecture

Within CarTALK there will be three different implementations of the reference architecture (in demonstrator vehicles of DaimlerChrysler, CRF and TNO) that will not be discussed in detail here. Within a combined demonstration of the CarTALK system at the end of the project in 2004 these three demonstrators should show the feasibility of the reference architecture and the interoperability of different reference architecture compliant implementations. The process to reach this combined demonstration is briefly shown in figure 5.

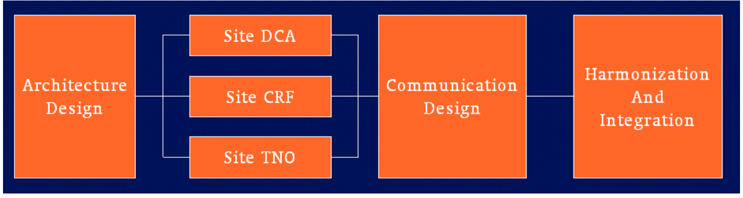

Figure 5. Coordination of partner implementations for the final demonstration

CBLC DEMONSTRATION SYSTEM

The final CarTALK demonstration system aims to show the merits of vehicle-to-vehicle communication in conditioned real life situations during a demo-day at the end of the project in 2004. In this demonstration, vehicles of the project partners will be able to co-operate in scenarios to be specified. In these scenarios vehicles can be active, which means that the application is actually run in the vehicle, or passive, which means that the vehicle does not support the application, but it still is part of the communication network and it supplies the data necessary for active vehicles. For the CBLC cluster, active vehicles are provided by DaimlerChrysler and TNO, whereas CRF will provide passive vehicles.

At this stage of the project the target demonstration system has not been implemented yet. However some steps to reach the final system have been taken, as will be described in the following sections. It will start with a description of the current demonstration systems at TNO and DaimlerChrysler. Subsequently it will further detail into the localization module (see figure 3) as developed by both partners. Finally TNO's co-operative controller for Stop&Go applications, as part of the on-board processing module, will be described.

Current demonstration systems at TNO and DaimlerChrysler

For efficient application development a demonstrator set-up containing a minimum set of necessary hardware has been developed by *TNO* [1, 4]. This set-up is different from the target CarTALK system and therefore is considered a work-around system for the purpose of application development. As a tool for application development and for displaying the preliminary functionality of the CBLC system at demonstrator level it has proven to be well suited [1, 4]. The configuration consists of three test vehicles as depicted in figure 5.

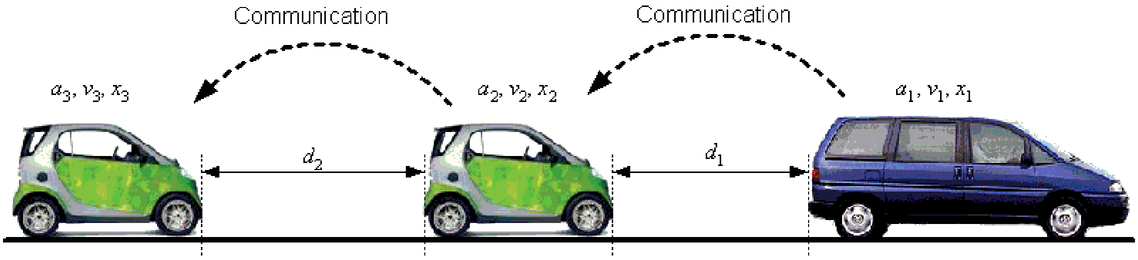

Figure 5. TNO configuration for application development with vehicles transmitting position, velocity and acceleration data in the upstream direction

The vehicles communicate via an infrared connection up to a distance of 300m. The front vehicle, a Peugeot 806, is used as the lead vehicle on which two Smarts anticipate. The Smarts have an electronically controlled automatic transmission and electronic throttle as standard equipment. In addition a brake actuator that mechanically pulls the brake pedal has been integrated. The on-board computer platform is based on a PC-104 processor board running real-time Linux as operating system. Furthermore all vehicles are equipped with differential GPS (dGPS), accelerometers in longitudinal and lateral direction and a velocity sensor, mounted at one of the rear wheels of the vehicle. During the course of the project the two Smarts will be upgraded according to the CarTALK specifications with respect to the communication system and system architecture.

DaimlerChrysler provides two vehicles to the project with functionality of vehicle 1 and 3 according to figure 1. Vehicle 1 is a Smart that does not possess any vehicle control facilities and serves only as communication partner with positioning and communication abilities. The Smart is equipped with a single laptop with Linux that executes all CarTALK relevant software. Vehicle 3 is an E-Class with longitudinal and lateral control capabilities. According to the CarTALK reference architecture a very reliable system (PowerPC, LynxOS) is used as a gateway between the OEM and the open system part. The system runs all safety and time critical tasks as well as watch dog functionality. All additional software like communication, positioning and high level control components is operated on an additional PC with real-time Linux.

Positioning technology

A positioning system that is used for control purposes has to be accurate, robust and must provide position data in real-time. In order to allow for longitudinal control of a cluster of interacting vehicles, state information concerning position, velocity and acceleration of preceding vehicles is exchanged. With this information each individual vehicle can determine headways and velocity differences with other vehicles within its range of influence. Eventually with this information each vehicle can generate a world model representing the traffic scene from its own perspective. Two possible design alternatives have been identified in the specification phase of the CarTALK system:

- Each vehicle is responsible for determining its own position including dead reckoning. Only filtered positioning information is exchanged between vehicles.
- Vehicles exchange raw position data and each vehicle may or may not apply filtering algorithms for dead reckoning.

The first design alternative imposes strict requirements on sensors and positioning algorithms of the vehicles. Less equipped vehicles that can not provide accurate dead reckoning results could cause undesired control effects in others. A strong advantage of the first approach is that less computation power is needed and more accurate filtering results can be achieved. It is efficient because it requires only to apply dead reckoning for the own vehicle data, and it is more accurate because more accurate models and sensor data from vehicle sensors may be used timely (without communication delay) that is not communicated via the communication link. For demonstration, the first approach is chosen where each partner uses different filtering algorithms, in order to identify the effects of diverse positioning algorithms on the overall performance.

For headway determination of the *TNO demonstrator vehicles*, the global position obtained by dGPS has been used as a start. However the update rate of dGPS (1Hz) is too low for vehicle control and the accuracy does not comply with the requirements of time-critical traffic situations. To obtain a higher update rate and a higher accuracy, dGPS signals have been complemented with inertial sensor data: acceleration in 2 directions and velocity. The subsequent sensor fusion is performed by an Extended Kalman Filter (EKF), in such a way that temporary dGPS losses are handled. The EKF is a state estimator that is based on a kinematic model of the vehicle and provides an estimate of the position with a frequency of 50 Hz [5]. The estimated states include longitudinal and lateral position, heading and velocity. Furthermore three error states have been used. Two error states that estimate the bias of the longitudinal and lateral accelerometer and one error state that estimates the error in the velocity sensor. Figure 6 gives a schematic overview of the EKF related to the other system modules.

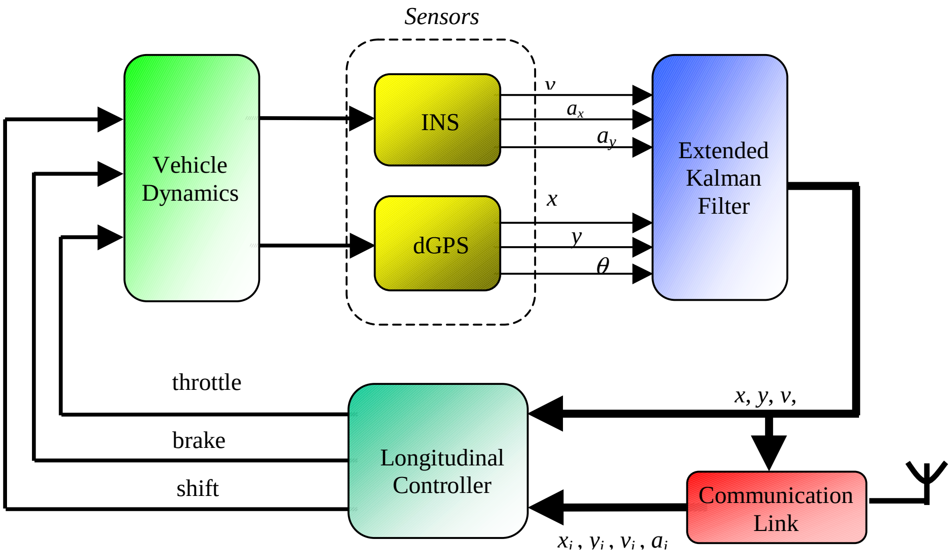

Figure 6. Overview of the Extended Kalman Filter as part of the TNO demonstration system

In the *assisting system department of DaimlerChrysler* a sensor independent fusion and scene representation approach is developed. In this architecture each sensor is encapsulated in logical sensor abstraction that provides uniform interfaces to the fusion and scene representation. The fusion and scene representation architecture basically serves a uniform interface where upon various applications can be integrated. Such an approach observes higher robustness and fault tolerance through concurrently arranged sensors. Particularly, in CarTALK the information of the radar and the communication sensors will be merged to a common view of the overall situation as indicated in figure 7.

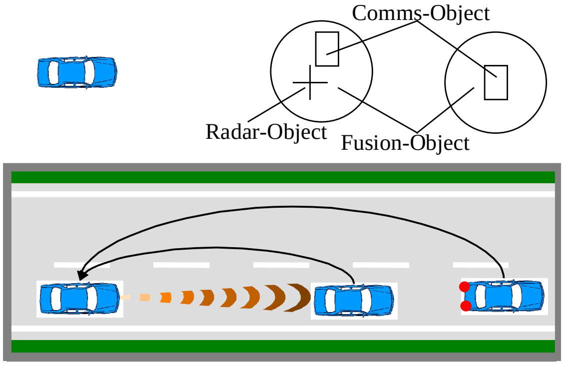

Figure 7. Fusion of radar and communication sensor data in the DaimlerChrysler system

DaimlerChrysler also uses an Extended Kalman Filter approach for dead reckoning. In this context several Kalman Filter models have been implemented and compared. The models use different sensor data e.g. for yaw-rate (gyro-sensor vs. wheel-rotation based calculation) and different error compensation states (e.g. for wheel diameter). Investigations on a test track with high precision map information have shown that each model has advantages and disadvantages, so that further research will be performed in the field on multi-model Kalman-Filter approaches.

Co-operative controller

When each vehicle is able to determine its own state and the state of vehicles within the (ad-hoc) vehicle cluster, a co-operative control strategy can be developed. The different partners can develop different strategies for their vehicles under the condition of stability when different vehicles are co-operating in one cluster. To assure stability, compatibility tests at vehicle control level will be performed in the ongoing project.

For the *TNO vehicles* two hierarchical levels are distinguished: an inner and outer loop, as depicted in figure 8 [7]. The outer loop corresponds to driver behavior and the inner loop to vehicle dynamics. The two loops can be designed separately, which allows to uncouple complexities during the design of both loops.

The controller design for the *DaimlerChrysler vehicles* is in the specification stage, wherefore only a basic outline can be given on the approaches used in this project. Two different controller strategies are taken into consideration. The first uses the ordinary ACC control system as a basis and processes additional CarTALK sensor information in an outer control loop. The second involves complete controller design that has been optimized to multi-object ACC. Final results will be available due to the end of project in July 2004.

The rest of this section will describe the control strategy developed at TNO, graphically represented in figure 8.

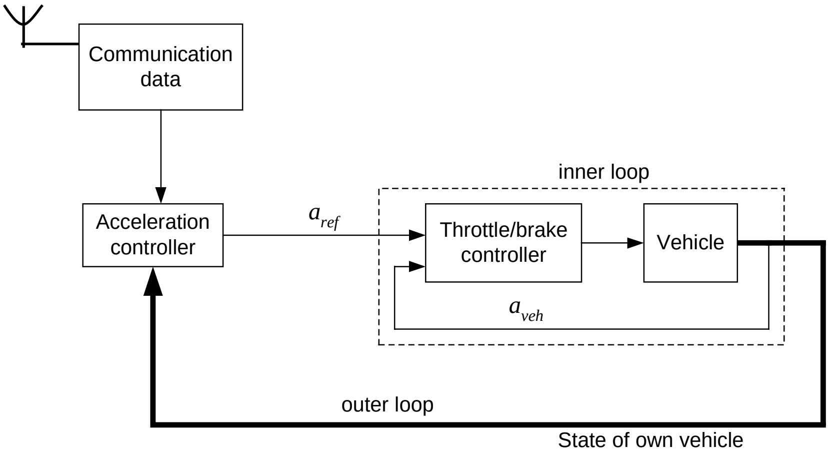

Figure 8. Control loops (inner and outer) used for longitudinal control of the TNO vehicles; a_{ref} *= target acceleration,* a_{veh}*= actual acceleration*

The outer-loop controller specifies the vehicle's target acceleration. This acceleration results from the co-operative control algorithm that will be discussed next. The inner-loop controller has to obey the acceleration set-point provided by the outer loop as fast as possible. The control objective of the outer loop is to keep a target headway to all relevant vehicles in front. In this case there are only two relevant vehicles; according to [8] this may go up to an estimated maximum of five. The target headway is calculated by:

$$d_{ref} = d_0 + h v_{veh} \tag{1}$$

where d_0 is the minimal headway between vehicles, implemented as a safety margin, v_{veh} is the vehicle's velocity and h is a time headway that can be adjusted slightly to speed differences in order to achieve the desired control performance. For three interacting vehicles the control set-up has been visualized in figure 9. As part of the co-operative driving principle, vehicle 3 evaluates information of vehicle 2 and 1 for optimal vehicle control. In order to reach the target headway with respect to both predecessors, vehicle i (i=3) will determine a target acceleration with respect to vehicle i-1 and i-2 separately according to:

$$\begin{aligned} a_{ref,i-1} &= c_1 a_{MND,i-1} + c_2\left(d_{i-1} - d_{ref,i-1}\right) + c_3\left(v_{i-1} - v_i\right) + c_4\left(a_{i-1} - a_i\right) \\ a_{ref,i-2} &= c_1 a_{MND,i-2} + c_2\left(d_{i-2} - d_{ref,i-2}\right) + c_3\left(v_{i-2} - v_i\right) + c_4\left(a_{i-2} - a_i\right) \end{aligned} \tag{2}$$

where the coefficients c_2 and c_3 are proportional and differential gains, and the terms involving the coefficients c_1 and c_4 correspond to a feed-forward action. Tuning of the different parameters is preferably done by making the outer loop behavior correspond to 'natural or acceptable driver behavior'. For this reason also the 'minimal necessary deceleration' (MND) according to [1] has been applied when relatively severe braking is necessary.

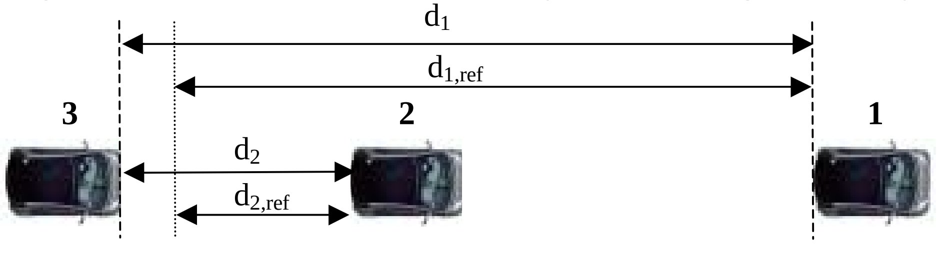

Figure 9. Vehicle separation as control target for the outer loop in co-operative driving

The target acceleration value commanded to the lower level controller of vehicle 3 is calculated according to:

$$a_{ref} = \begin{cases} \min\left(a_{ref,2}, a_{ref,1}\right) & \text{if } \min\left(a_{ref,2}, a_{ref,1}\right) < 0 \\ \max\left(a_{ref,2}, \left(w \cdot a_{ref,2} + (1-w) \cdot a_{ref,1}\right)\right) & \text{otherwise} \end{cases} \qquad (3)$$

where w is a weighing factor ($w \in [0.5; 1]$). A subdivision has been made into negative and positive accelerations. For deceleration (Stop) the minimal value of the two accelerations is taken. For acceleration (Go) the maximum of $a_{ref,2}$ and a weighted mean value of the two accelerations is taken. As a first estimation for w the value 0.5 has been chosen. For safety reasons priority is given to negative accelerations. If for example $a_{ref,2}$ is positive and $a_{ref,1}$ is negative or vice versa then the Stop-action will apply. A smooth transition between these two accelerations has been implemented to prevent sudden changes of reference acceleration.

EXPERIMENTAL RESULTS

Conditioned experiments have been performed to analyze the functionality of the current version of TNO's CBLC system. For these experiments the demonstration set-up according to figure 5 has been used on a closed test track, provided by the Dutch Ministry of Transport, Public Works and Water Management. A Stop&Go scenario at different velocities has been tested. The front vehicle accelerated from a standstill position to a steady velocity of 15 m/s and after about 37 seconds it started decelerating to a standstill position. This routine was repeated with a steady velocity of 17.5 m/s and with a higher deceleration at the end of the maneuver. The Smarts can operate in *active control mode* and *informative mode*. In the active control mode brake and throttle are controlled automatically, in the informative mode the driver reacts on HMI signals [1]. For a most challenging technological and functional exploration of the system's performance, active control mode results are presented.

The first outcomes of the experiments show the feasibility of the combined EKF and vehicle-to-vehicle communication approach. A headway determination with a mean error relative to the real distance of 1~1.5m could be achieved. This was found to be sufficient for the tested application when applying a proper safety margin. In figure 10 the inter-vehicle headways as derived from the EKF positions of the individual vehicles are presented.

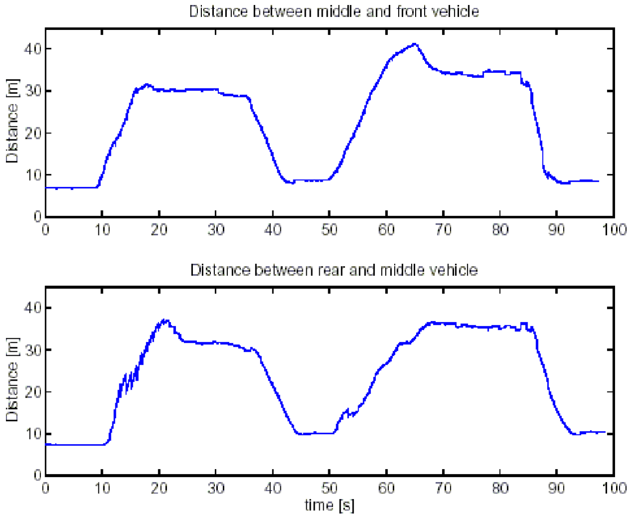

Figure 10. Inter-vehicle headways during the Stop&Go maneuver

The distances between the successive vehicles at standstill are about 8 m, corresponding to the applied safety margin. Furthermore the headways are constant during the steady state periods, which is confirmed by figure 11. This figure presents the velocity profiles of the three vehicles and shows that the velocities become equal at the two steady state situations. Furthermore the following vehicles react with minor delay on acceleration or deceleration actions of the front vehicle. Figure 10 and 11 show that over a distance of about 1 km the vehicle-following behavior of the two Smarts was very successful. This applies to steady state situations and to situations in which the front vehicle initiated a disturbance.

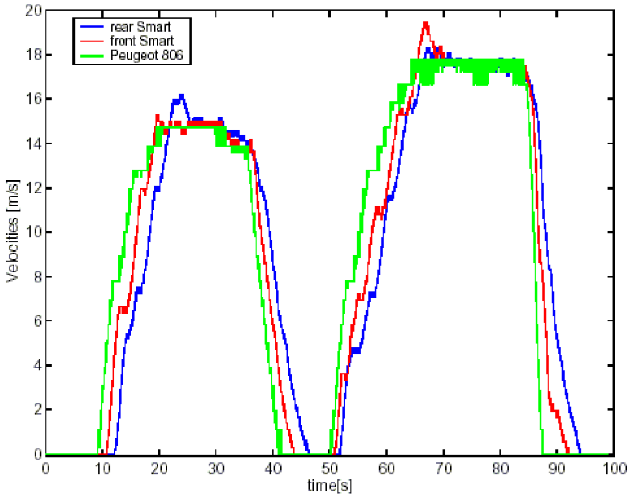

Figure 11. Velocity profiles of the three test vehicles during the Stop&Go maneuver

Figure 12 presents the acceleration profiles of the three vehicles. It shows that the two following vehicles react instantaneously to decelerations of the front vehicle at t = 37s and t = 85 s. The fluctuating acceleration signal is caused by the automatic gear shifting behavior of the Smart. The figure also shows that the deceleration level of the following vehicles is considerably less than the front vehicle. This complies with previous results obtained in the CarTALK project [1].

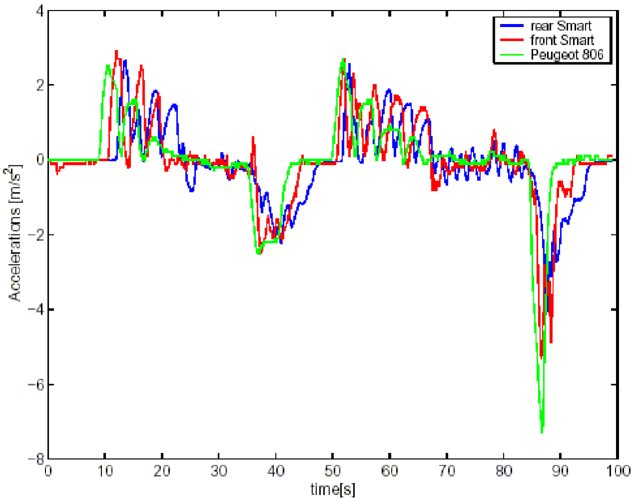

Figure 12. Acceleration profiles of the three test vehicles during the Stop&Go maneuver

CONCLUSIONS

The main objectives of EC 5th framework project CarTALK2000 are the development of co-operative driver assistance systems and the development of an ad-hoc vehicle-to-vehicle communication network preparing a future standard. In this paper ongoing work regarding the target system, that will be ready for demonstration at the end of the CarTALK project in 2004, has been described. The short-term target communication system will be based on the 802.11b WLAN standard, the long-term system will be based on UMTS. The system architecture will be based on an open CarTALK reference architecture that supports partner specific implementations.

Ongoing developments of CBLC applications have been presented. A co-operative Stop&Go system has been implemented in the current version of TNO demonstration vehicles. These vehicles are not yet equipped according to the final CarTALK specifications. However to support application development and to explore functional and technological feasibility of the co-operative driving principle, these work-around demonstration systems are well suited.
A sensor fusion approach of differential GPS, velocity and acceleration signals based on Extended Kalman Filtering has been applied. With all individual cars performing their own filtering and subsequent communication to other vehicles, an inter-vehicle headway determination with an accuracy of 1~1.5m could be achieved. This appeared sufficient for the tested Stop&Go application.

Conditioned experiments with three vehicles showed that the CBLC system works properly. The 2 following vehicles were able to follow the front vehicle automatically and they reacted much faster to sudden changes in accelerations of the front vehicle than a human driver would do. These outcomes support earlier results regarding improved driver support and increase of traffic safety by compensation of the human reaction time [1]. They also support the perspective of optimized traffic flow by the demonstrated vehicle-following behavior. The longitudinal controller can be further optimized for improved comfort at higher speeds and for acceptable driving characteristics for a wide range of different drivers. For using the system in an informative driving mode, more attention has to be paid to human machine interfacing.

In next stages of the project the applications will be further developed and tested. Important points of attention will be the implementation, testing and evaluation of the CarTALK system. In the final phase of the project in 2004 there will be a demonstration with TNO, DaimlerChrysler and CRF cars. To do this the target CarTALK communication system will be operational in all vehicles. Traffic simulations and socio-economic assessment of the system will further clarify market perspectives. Final results will be presented in July 2004.

ACKNOWLEDGEMENTS

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