Available online at www.sciencedirect.com

ScienceDirect

Transportation Research Procedia 14 (2016) 2237 – 2244

Transportation Research Procedia

www.elsevier.com/locate/procedia

6th Transport Research Arena April 18-21, 2016

Towards manoeuver negotiation: AutoNet2030 Project from a car maker perspective

F. Visintainer [a,*], L. Altomare [a], A. Toffetti [a], A. Kovacs [b], A. Amditis [c]

[a]*Centro Ricerche FIAT, Strada Torino 50, 10043, Orbassano (TO), Italy*
[b]*BroadBit Energy Technologies s.r.o., Eötvösova ul. 12., 945 01, Komárno, Slovakia*
[c]*Institute of Communication and Computer Systems, Iroon Polytechniou St. 9, 15773 Athens, Greece*

Abstract

Vehicle-to-vehicle and vehicle-to-infrastructure communication (also known as V2X) can augment vehicle perception, which is a key factor in Advanced Driving Assistance Systems (ADAS) as well as in the future scenario of Automated Driving. The European project AutoNet2030 demonstrates how the combination of V2X and on-board sensors makes vehicle control, manoeuvring negotiations and interaction between vehicles more efficient and reliable. The target driving scenario involves a group of vehicles moving in a coordinated way, thanks to vehicle-to-vehicle communication. This requires a novel set of messages, to transmit vehicle status, trajectories and manoeuver intentions, such as lane change, within the group. Another research topic is the interaction between the on-board system and the driver (Human Machine Interaction, HMI), considering both the novel manoeuvre coordination concepts, and the gradual introduction of automated functions from an end user perspective. These concepts are integrated into prototype vehicles, which are going to be experimented in the next future to understand the full system potential.

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)

Keywords: manoeuver negotiation; vehicular communication; automated driving; Human Machine Interaction

* Corresponding author. Tel.: +39-0461-412318 ; fax: +39-0461-412325.
E-mail address: filippo.visintainer@crf.it

Peer-review under responsibility of Road and Bridge Research Institute (IBDiM)
doi:10.1016/j.trpro.2016.05.239

1. Introduction

Automated manoeuvring capability will be one of the most impacting technologies on future mobility, as it will lead to safer driving conditions, improved comfort as well as more efficient traffic management. Vehicle manufacturers' research and development efforts are tackling different aspects of automated driving, including sensing, vehicle control systems as well as human interaction. However, highly autonomous vehicles cannot yet be considered as a foreseeable target for mass market deployment in this decade. Rather, the deployment of integrated Advanced Driver Assistance Systems (ADAS) with growing levels of automated manoeuvring functionalities is envisaged. This translates in the so-called evolutionary approach, which considers increasing levels of automation, with reference to its classification in SAE standard J3016 (2014), and comprehensively evaluates each new automotive function, technology or system under the realistic perspective of future large-scale deployment.

Vehicular communication technology is expected to be of increasingly-high interest for the automotive industry along the years to come, as reported in a position paper by Visintainer et al. (2015). Its potential benefits are huge, considering that communication on the one hand can extend the on-board sensing capability by exploiting available information from neighbouring vehicles, as described by Obst and Reisdorf (2015); on the other hand it can enable *cooperation* among vehicles, namely the negotiation of manoeuvres is expected to find a place in automated driving scenarios. In particular, vehicular networking based on IEEE802.11p (ETSI ITS G5, SAE DSRC) is being investigated from several perspectives: the integration within the in-vehicle architecture, the secure and reliable usage of information by ADAS control systems, the aspects concerning data exchange, the multi-source data fusion, etc.

Another aspect when addressing automated driving is the Human Machine Interaction (HMI) given that the drivers' role and relationship with the automated vehicle in future scenarios will be generally different than it is today. As a general guideline, the user should receive information in a comfortable way, minimizing distraction and avoiding superfluous information. In addition, the novel cooperative scenario has to be considered: a vehicle exchanges information with its neighbours and processes it autonomously, eventually taking a manoeuvring decision. The output is either a driving suggestion on the dashboard HMI, or, in the future, the direct vehicle control. The HMI design should therefore clearly distinguish between events that are invisible to the user, such as intermediate manoeuvre negotiation, from events that need to be communicated to the driver or even need her/his intervention.

The EU co-funded AutoNet2030 project, being introduced through this article, addresses V2X communications in manoeuvre negotiation taking place within groups of vehicles. The approach was described by La Fortelle et al. (2014). The exchanged V2X (ad-hoc) messages allow for more efficient and coordinated driving even in complex and crowded traffic situations. Their definition based on the extension of current standards, enables group strategy logics where the manoeuvre-controller decisions are essentially driven by those messages. After the on-board processing, either an indication is given to the driver or a specific autonomous manoeuver is undertaken. As a result, smooth interaction is foreseen in different scenarios, involving cooperative vehicles with different automation levels. Indirectly, also non-cooperative vehicles are considered, since they are detected by the on-board sensors of the AutoNet2030 vehicles. With the aforementioned approach, Centro Ricerche FIAT, an FCA company, is evaluating together with project partners the potential of the AutoNet2030 technological improvements and in particular those related to communication technology.

2. Target scenario

Convoy driving can take place when two or more vehicles share some similar goals during a certain time period, driving in a group formation on a given road segment. Convoy driving is characterized by higher manoeuvring autonomy than platoon driving, i.e., vehicles in a convoy negotiate manoeuver only with their direct neighbours, without any centralized control of the group. Such coordinated driving mode allows inherently safe lane change execution, safe distance keeping, as well as the flexibility of additional vehicles merging into the group or leaving the group.

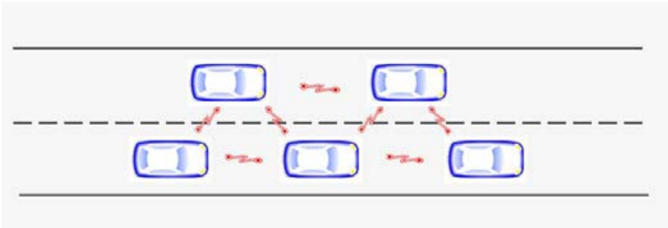

Fig. 1. Group of vehicles in a convoy, each one negotiating with its surrounding neighbours.

AutoNet2030 tackles all the phases of this scenario and defines, for each of them, the underlying strategies based on vehicular communication. Hereafter the single phases are briefly summarized.

There are two possible approaches to designing the above-listed single phases. The first approach is to take no assumption about the underlying manoeuvring control algorithm of neighbouring vehicles, and to design a rather lengthy transaction for each phase's implementation, including complex negotiations, exception handling, and fall--back scenarios.

The second approach is to assume that all neighbouring are vehicles running the same high-level manoeuvring control algorithm, possibly with just parameterisation differences. In this second approach of having the same high-level control, both the control algorithm and the communication transactions design become much more simple and reliable. Therefore we chose this approach of same control algorithm across the group of vehicles, and chose a convergent Laplacian-type manoeuvring control algorithm for maintaining safe distance among group members during any event, as in the publication by Marjovi et al. (2015).

Having the same high-level control algorithm does not imply any restrictions on the low-level control algorithm, which is responsible for the precise execution of manoeuvring commands. In fact, the AutoNet2030 project shall demonstrate the same high-level control running over different low-level controllers in various test vehicles, and shall validate the corresponding interoperability. This approach implies the assumption that vehicle manufacturers shall agree upon a consensus high-level manoeuvring control algorithm for convoy driving. We encourage the definition and subsequent standardisation of such high-level control algorithm for convoy driving.

Table 1. Convoy driving phases.

Phase	Description	Vehicular communication
Creation	A vehicle, the initiator, recognizes the opportunity to form a new convoy.	The initiator sends a joining advice to other vehicles in the vicinity and neighbours acknowledge the inclusion
Joining	Another vehicle intends to join the convoy.	From beacon messages of neighbour vehicles, the vehicle identifies a convoy and its driving purposes. The vehicle decides to join it and requests to join.
Keeping	A vehicle keeps driving within a convoy.	Ad-hoc messages are exchanged in case of lane changes within the convoy.
Leaving	A convoy member decides to leave.	The vehicle leaves and informs convoy members.
Dissolution	A member decides to leave and the convoy dissolves, due to insufficient number of vehicles.	Similar to previous one.

Each single phase of convoy driving, reported in Table 1, constitutes a key element of interest for single manoeuver control. Centro Ricerche FIAT is focusing on the evaluation of specific elements, such as automated lane changing and automated distance keeping. In this context, vehicular communication is both a means to enhance perception robustness and thus the safety conditions, through the generated information redundancy, but also a means to negotiate manoeuvers.

3. Vehicular communication

The scenario described in the previous chapter requires a local, low-latency data exchange between direct neighbour vehicles that implies the need for dedicated short range communication based on the IEEE802.11p standard.

However, current message services as defined in ETSI TS 102 637-2 (2014) are not sufficient, as there is a need for the following additional information:

- beaconing messages with state and trajectories of all vehicles
- join/leave notification messages, with an acknowledgement of receiver-side processing
- lane change messages carrying lane change plan
- local graph modifications messages, including updated topology of the vehicular ad-hoc-network

Although the goal is to evaluate vehicular communications as a whole, one of the main topics relates to the extension of ETSI Cooperative Awareness Message (CAM) beacons, for two reasons. Firstly, CAM are periodically broadcasted by-default and carry a full set of vehicle data, including current position, speed and yaw rate. Therefore, these messages have a huge potential as new sensing source regardless the application case or the ADAS function. Secondly, a number of demanding project-specific requirements on beaconing have emerged, and consequently highlighted the need for a CAM extension in the case of automated cooperative vehicles. Data requirements regard the inclusion of predicted trajectories and control parameters such as distance to the preceding vehicles, target speed set by automated driving, etc. Frequency requirements demand that CAMs should be transmitted at the highest possible frequency in specific situations such as the convoy. The proposed extension, published by AutoNet2030 consortium (2015), foresees two possible operating modes of the vehicle. When the vehicle is in the so-called *normal mode*, it sends standard CAM on the control channel, at a frequency of 1-10 Hz and depending on congestion control. When it changes to the so-called *high awareness* mode, it sends also extended CAM messages on a separate channel, including a minimum set of parameters sent at the maximum frequency (10Hz) and other control parameters such as trajectory prediction at lower frequency e.g., 2 Hz. Further insight on communication requirements can be gained from the work by Hobert et al. (2015).

4. Human machine interaction

When facing vehicular networking for automated driving functions, one of the first challenges is how to interact with the driver. The adopted approach has been to start from a reference scenario consisting of partially autonomous vehicles, i.e., to start from the lower automation levels reported in SAE J3016 (2014). A multidisciplinary work is being carried out involving, besides engineering, software and hardware experts as well as interaction and cognitive HMI experts. The aim is to design a user interface able to take into account both the driver comfort and the easiness of use in advised manoeuvring.

The HMI development process started by considering the driving scenario, e.g., the aforementioned convoy driving, and analysing the related functional Use Cases from a user/driver point of view. Each Use Case has been broken down into a flow of events and actions the user needs to cope with, while driving. This analysis has been conducted considering both automated and manual driving conditions (all Use Cases correspond to driving conditions, none of them to stationary conditions). According to the role of the user, the following classification can be made:

1. Use Cases invisible to the user: system actions and communication with other vehicles that do not affect the driver situation awareness, are not useful for the driver or could be distracting
2. Informative Use Cases: system information or advised manoeuvres the driver needs to be informed about
3. Interactive Use Cases: the user will be able to interact with the HMI system

Fig. 2. Head Up Display on top of the instrument cluster (left) and Tablet Display (right).

Following these requirements a distributed HMI has been designed using two devices (Fig. 2): a Head-Up Display[1] (HUD) in front of the driver as main display, and a touchscreen Tablet as secondary display in the central console.

This HMI setup allows the driver to receive the most important information and manoeuvre advice on the HUD ("what to do" advice), while the secondary display allows the user to have both in-depth information (e.g., the reason why the system is suggesting to follow a determined speed is because of a congestion in, for example, 5 km) and interactive button (e.g., switch button between manual and automated mode, when available). In order to maximize driver's safety, the interaction button will be available during safe conditions only.

For each display used (HUD, dashboard secondary display), a layout has been defined to cope with the different kinds of display-content, i.e. visual elements. Defining a consistent organization, drivers can more quickly understand how information is organized and presented.

The graphical representation on both devices and in particular on the HUD has been conceived by considering the essential information-bearing elements for the driver, in order to reduce information cluttering. Moreover, when possible, text messages have been avoided on the HUD.

All the messages displayed on the HMI have been defined according to a predefined syntax structure and prioritized (for projection) with respect to a designed HMI logic that accounts for their significance.

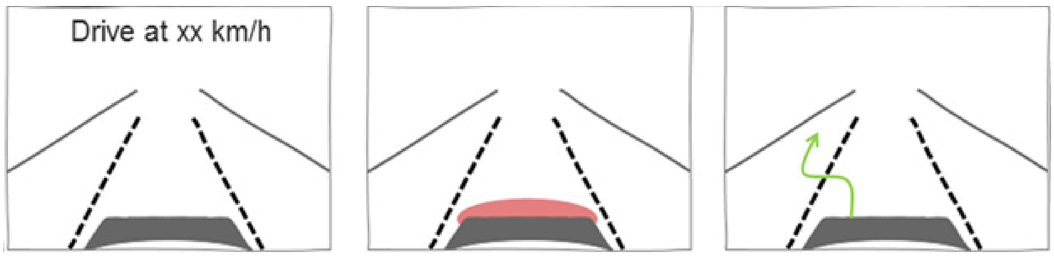

Fig. 3. Head Up Display wireframe examples.

[1] By courtesy of Panasonic U.S.

Following the ergonomics guidelines ISO 15008:2009, both text and icons size have been dimensioned with respect to the visual field positioning; and always working with consistency in mind, different kind of punctuations have been used to highlight information of different urgency level. A reference is the work by Stanton et al. (2014).

Interaction logics and flow have been created with a linkage to the messages. In this way it is possible to anticipate all the possible paths that users could follow in completing a task. The interaction deployment has been created considering automated manoeuver scenarios, for instance convoy driving.

5. Deployment

The following picture (Fig. 4) shows the vehicle on which the system is installed.

Fig. 4. AutoNet2030 demonstrator vehicle.

The set-up reflects the AutoNet2030 functional architecture. A central unit gathers sensing and positioning data, handles the cooperation with other vehicles, evaluates driving conditions and provides feedback to the driver on suggested manoeuvers. The same feedback can in a later stage be the input to vehicle automated controls.

The core project software, provided by the AutoNet2030 consortium, is installed on an embedded computer for automotive.

Vehicle manoeuvre data are available from the CAN bus, through a gateway software module, which translates the car signals of interest, such as speed, yaw rate, turn indication, etc., to a format defined in the project. Frontal perception in the convoy driving is performed by a LIDAR sensor, namely a time-of-flight based 2D Near-Infrared laser scanner for automotive. The LIDAR provides a list of detected objects, along with relative position and speed, length, width and orientation of the object and an estimated category classification (e.g., pedestrian, car, truck, bike, etc.). Similarly to the CAN data, a gateway adapts the data format to a common project format. For both CAN and LIDAR data, the authors' approach has been to design flexible gateway modules which can easily be reconfigured in case of changes in input or output data specifications.

The car absolute position is obtained through a GNSS receiver with Dead Reckoning, embedded in the On-Board Unit. In addition, another GNSS with Real Time Kinematic (RTK) is available for centimetre level precision. The comparison of measurements by both devices will help us understand the dependence of the system performance on positioning accuracy.

Vehicle-to-vehicle communication is provided by an ITS-G5 Communication Control Unit, implementing IEEE 1609 & ETSI TC-ITS Network Layer software. A dedicated firmware by Hitachi enables the networking and messaging protocols defined in the project.

For the Human Machine Interaction, as previously mentioned a twofold approach was followed by the authors, deploying both a Head-Up display and a secondary display (7-inch Tablet). A dedicated HMI manager software was specifically developed, which allows either to combine the devices or to use them alternatively. This solution will enable future comparative assessment of drivers' perception using different devices.

The following block scheme shows how the functional architecture is deployed in the physical subsystems.

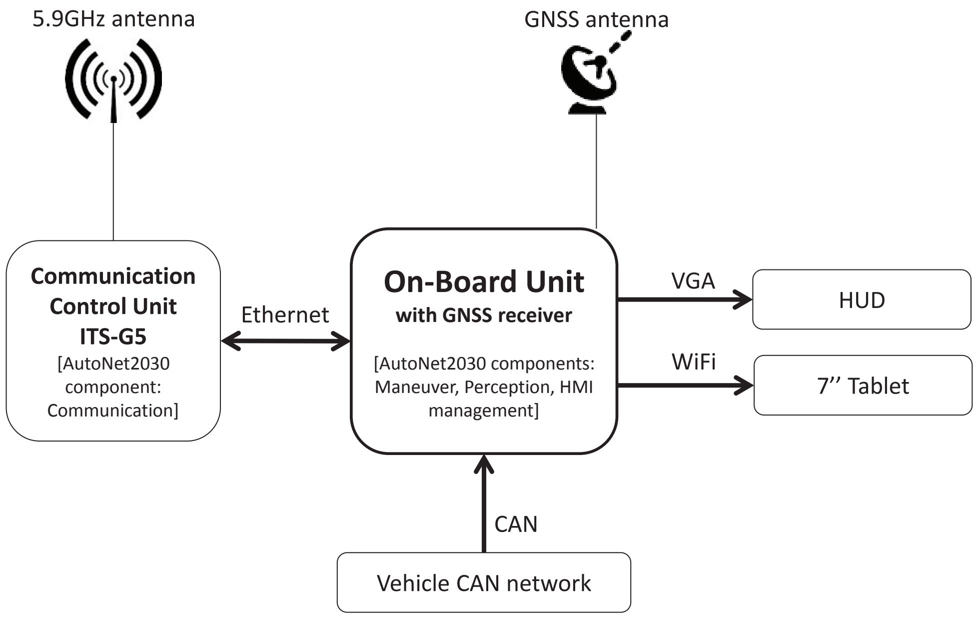

Fig. 5. System architecture.

6. Conclusions and next steps

What has been presented here is the AutoNet2030 project activity from the viewpoint of a car manufacturer adopting an evolutionary (rather than revolutionary) approach towards automated driving. This means, that the possible adoption of project novelties for ADAS and automated functions should be considered with an incremental plan and should proceed along with a thorough validation of results and cost/benefits assessment, which are expected to follow as next project activities.

The scenario presented in this paper is the Convoy Driving, which enables the group management of autonomous vehicles, while guaranteeing relative autonomy of manoeuvre of each individual vehicle, including joining and leaving. This scenario has been selected because it is considered to be the most promising method for the introduction of automated passenger car driving on highways, in an inherently safe manner. The corresponding cooperation among the involved vehicles needs additional V2X messaging specification. The main interest of a car maker in this scenario is to evaluate the single phases and manoeuvers, such as automated lane change, automated distance keeping, etc., maintaining the highest safety conditions for the vehicles. The focus of the authors has been on two main parts of the AutoNet2030 body of work: the first is represented by Cooperative Awareness Messages (CAM), that carry full sets of vehicle information to be exchanged and thus enhance the vehicle perception; moreover, they can be used in a flexible way also in other scenarios such as the vehicle's communication with roadside units, as described by Santa et al. (2013). The second part is the Human Machine interaction, considering different cases of interactions from information to driver's intervention. This has required a joint effort of technology experts and ergonomists for the definition of a dedicated set of messages to be displayed to the end-user on the vehicle. User testing on the designed HMI should be addressed in the future, to evaluate the driver's experience.

The overall AutoNet2030 system has been set-up on a vehicle demonstrator. It is equipped with a GNSS lane level positioning, a frontal LIDAR and a Vehicular Communication Control unit, a central processing unit implementing the cooperative algorithms, and finally an HMI system. This manually-driven prototype, together with other vehicles, will be tested on the road to evaluate the AutoNet2030 performance in manoeuver negotiation and its capability to meet all safety requirements. Once the technology benefits will become clear, most likely at the project's latest stages (or even after its completion), the integration of communications, manoeuvring decision strategies, vehicle control and actuations will be enabled.

Acknowledgements

This paper describes activities that are part of the European project AutoNet2030 "Co-operative Systems in Support of Networked Automated Driving by 2030" co-funded by the European Commission. Paper's authors would like to acknowledge project partners for the effective cooperation and the respective co-funding bodies. We acknowledge the kind support of CRF colleagues Luisa Andreone, Marco Darin, Antonella Masala and Cristina Zoldan.

References

AutoNet2030 Public Deliverable D3.2 by Hobert, L. et al., 2015. Specifications for the enhancement to existing LDM and cooperative communication protocol standards.

ETSI TS 102 637-2, 2014. Intelligent Transport Systems (ITS); Vehicular Communications; Basic Set of Applications; Part 2: Specification of Cooperative Awareness Basic Service.

Hobert, L., Festag, A, Llatser, I., Altomare, L., Visintainer F., Kovacs A., 2015. Enhancements of V2X Communication in Support of Cooperative Autonomous Driving. IEEE Communications Magazine, Volume: 53, Issue: 12, pp. 64–70.

ISO15008:2009. International Organization for Standardization. Road vehicles – Ergonomic aspects of transport information and control systems – Specifications and test procedures for in-vehicle visual presentation. Genève: ISO.

La Fortelle, A., Qian, X., Diemer, S., Grégoire, J., Moutarde, F., Bonnabel, S., Marjovi, A., Martinoli, A., Llatser, I., Festag, A., 2014. Network of automated vehicles: The AutoNet2030 vision. In: Proceedings of the 21st World Congress on Intelligent Transport Systems, Detroit, Michigan, USA.

Marjovi, A., Vasic, M., Lemaitre, J., Martinoli, A., 2015. Distributed Graph-based Convoy Control for Networked Intelligent Vehicles. In: IEEE Intelligent Vehicles Symposium, pp. 138–143.

Obst, M., Reisdorf, P., 2015. Enabling Cooperative Automated Driving by Multi-Sensor Data Fusion with V2V Communication, 22nd ITS World Congress, Bordeaux, France.

SAE standard J3016, 2014. Taxonomy and Definitions for Terms Related to On-Road Motor Vehicle Automated Driving Systems.

Santa, J., Pereniguez, F., Moragon, A., Skarmeta, A. F., 2013. Vehicle-to-infrastructure messaging proposal based on CAM/DENM specifications. In: Proceedings of IFIP Wireless Days (WD)'13, pp. 1–7.

Stanton, N., Di Bucchianico, G., Vallicelli, A., Landry, S., 2014. Advances in Human Aspects of Transportation: Part I, Proceedings of the 5th AHFE Conference in Advances in Human Factors and Ergonomics, Las Vegas USA.

Visintainer, F., Darin, M., Saroldi, A., Da Lio, M., 2015. Connected Vehicles for Automated Functions: from Enhanced Perception to Negotiated Manoeuvres, 22nd ITS World Congress, Bordeaux, France.