Onboard Unit (OBU) in an ITS System on the Basis of Coopers Project

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ABSTRACT
This paper will present an On Board Unit (OBU), which is an integral part of planned ITS – acronym COOPERS. It will describe the structure, construction and components, ways of communication with the infrastructure (V2I) and with other vehicles (V2V), communication with on board information from CAN and OBD, usage of GPS signal, gyroscope, and user interface. The usage of OBU in the project enables to introduce new functionalities.

KEYWORDS: ITS architecture, ITS, OBU

1. Introduction

Assuming a complete set of requirements for the implementation of COOPERS services, including functional and non-functional ones, and an unlimited budget, one could construct ideal in-car and roadside equipment with perfect services fulfilling all on which the requirements are based.

COOPERS project vision:
Vehicles are connected via continuous wireless communication with the road infrastructure on motorways, exchange data and information relevant for the specific road segment to increase overall road safety and enable co-operative traffic management.

European road network faces a traffic demand increase up to 50% over the next 15 years. At the same time road operators have the national and European obligation to improve the level of service, to improve safety and to decrease the number of fatalities and injured persons in road accidents by 50% till 2010.
That is why new techniques and methods are requested to move increasing number of vehicles safe, efficient and environmentally sustainable through the existing network.

Co-operative systems enabled by enhanced telematics (vehicles and infrastructure) allow to handle the dense traffic safely and efficiently.

Complementing the current research on the in-vehicle technology and vehicle to vehicle communication (V2V), innovative solutions for the communication between infrastructure and vehicles (I2V) have to be established to explore these options targeting a better use of the available infrastructure capacity. Figure 1 presents a recommended COOPERS configuration – the In-car network + RSU:

- Communication technologies: Infrared, CALM 5, GSM/GPRS, DAB – broadcast communication, DVB-H – broadcast communication alternative to DAB, RDS-TMC – broadcast communication (comparison of existing RDS-TMC installations with DAB);
- In-car network: T&TT On Board Unit from ARS as an automotive PC to run the COOPERS services; Robust Positioning Unit (RPU) from PWP Systems for vehicle positioning; OBU – 3 from EFKON as the communication gateway; CAN connection; additional sensors like gyro-meter …;
- CAN/additional sensors. OBD-II (On Board Diagnostics) is an on-board diagnostic system which is used in several vehicles and which is mandatory for new vehicles sold within Europe (and USA).
- Infrastructure/ Roadside: roadside controller from SW ARCO (implemented by SMC/SW ARCO Motorway Controller); CALM Gateway module from EF-
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KON; Sensor Management from ASCOM will be used. The roadside configuration as posted above will only be installed when a local computing power is needed or IR communication is installed on the dedicated roadside. The existing roadside sensors may be used as they are. Especially if they are directly connected to the TCC, no change of the existing installation may be feasible. The CALM Gateway module is connected to the SMC. The information transferred to and from the SMC which has to be transmitted over short/medium communication technologies is forwarded by the SMC to CALM Gateway module or the TCC.

The project uses the cooperative synergy of existing technologies and equipment to attain the road safety improvement. However, the implementation of services efficiently and with adequate quality depends not only on the quality of the technology and technical devices themselves, but also on the availability of experience within the team of those COOPERS partners who are responsible for designing, development and testing the COOPERS subsystems.

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1.1. I2V Communication Link

DAB/DMB/DVB-H

Digital Audio Broadcast (DAB) is a technology to broadcast audio and many other types of digital services in several standardized manners. Its latest enhanced Digital Multimedia Broadcasting (DMB) is a standard to carry the content and enriched services to a mobile user, as well as the introduction of a more sophisticated audio codec. DAB/DMB is required for wide range communication. A lot of safety related information must be provided to all road users and DAB/DMB is the cheapest technology for this. Unfortunately it lacks the ability to respond to a received message. Alternatively to DAB the DVB-H technology will be implemented within COOPERS. This will be applied on test sites where DAB is not available.

CALM IR

CALM (Continuous Air interface, Long and Medium range) is a family of standards which determine a common architecture, network protocols and air interface definition for wireless communications using cellular second and third generation, infra-red, 5 GHz, and 60 GHz communications. Other air interfaces may be added at later date. These air interfaces are designed to provide parameters and protocols for communications in the ITS Sector, as follows:

- Data rates of 1 and 2 Mbit/s, the standard provides up to 128 Mbit/s.
- Vehicle speed in excess of 200 km/h.
- Communication distance up to 100m
- Latencies and communication delays in order of milliseconds.

CALM IR is a medium range communication and is the perfect complement to DAB/DMB and GSM/GPRS.

CALM M5

CALM M5 is the European/International version of American WAVE (Wireless Access to the Vehicular Environment) standard including IEEE 802.11p. When CALM M5 becomes available it would be a preferred medium to support the aspects of COOPERS. At first glance the technology should enable COOPERS services to be hooked on and therefore CALM M5 will be evaluated in the COOPERS project.

TPEG protocol

For the communication between TCC and OBU COOPERS needs a common message format and decides to use the TPEG (Transport Protocol Experts Group) specifications for this purpose. The TPEG is a bearer and language-independent TTI (Traffic and Travel Information) service protocol that has a unidirectional and byte-oriented asynchronous framing structure. There are basically two formats for TPEG messages – tpeg ML and tpeg binary. The difference between them concerns only the format and not the content, as both variants are designed to map on onto each other precisely. Therefore the differences concern mainly the size of the data used and the

Fig. 1. Modeling and simulation process flow in TRANSIMS
Source: [own work]
accessibility. As a lot of software tools and libraries already exist it is comparatively easy to handle messages in the XML format as long as there are hardware resources and bandwidth. However, in an area of limited resources, one can save memory and/or bandwidth by using the binary format. For this reason it is possible to use both. The TPEG is a modular toolkit and consists of the following applications:

- RTM – Road Traffic Information,
- PTI – Public Transport Information,
- Loc- Location referencing, used in conjunction with applications.

2. HMI – Human Machine Interface

A design of HMI is illustrated in Figure 2. General status panel displays the GPS status and current date and time. Concerning the event icons, thumbnails of the existing events are displayed in a minimized form. The currently active event thumbnail is surrounded by a brown rectangle. The thumbnail is automatically cleared on expiry of the event. Tapping on the thumbnail displays the corresponding event. The event details panel lists out the event information. It displays the events graphically. Instructions or recommendations are displayed on the red rectangle at the bottom of this panel. The orange arrow denotes that there will be more information. The planned route is displayed on the navigation panel. The current position and location of the vehicle is also displayed. The route is annotated with thumbnails of traffic events. The actual speed and the prevailing speed limit are also displayed on the navigation panel. The distance to the next turn is also shown, Fig. 3.

3. Automotive PC and in car network

The automotive PC, Figure 4, has the primary purpose to collect COOPER’s services. AP and the applications are created to test and validate the COOPER’s services.

The following services are defined:
- Weather conditions – to provide in vehicle, dynamic information to warn drivers of hazardous road surface conditions ahead caused by ice or frost;
- Fog warning – to provide in-vehicle, dynamic information to warn drivers of poor visibility caused by fog;
- Accident warning – to warn drivers of a road accident ahead with in-vehicle, dynamic information and inform the emergency service providers for efficient recovery;
- In-vehicle variable speed limit information – to provide drivers with real-time, in-vehicle information on appropriate speed for the current conditions, which are based on traffic flow, traffic speed, weather and others inputs;
- Lane banning (LB) – according to the type of vehicle and the network condition, to provide drivers with real time, in-vehicle information about lanes which are not accessible, e.g. HGV are not allowed to drive on the off-side lane on motorways. Also some network section has dedicated lanes for public transport;
- Keeping Lane (LK) – to provide real-time, in-vehicle advice for drivers not to change on specific road links;
- Auxiliary Lane Accessibility (ALA) – to provide real time, in-vehicle information to inform drivers on a specific motorway section about the availability of auxiliary lanes for emergency stopping or driving;
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- Traffic congestion warning (TCW) – to provide in-vehicle, dynamic, information to warn drivers of congested traffic ahead;
- ISA with infrastructure links – to inform/warn drivers of vehicle speed limit and help them match their speed to prevailing traffic/road conditions;
- Road charging to influence traffic demand – the aim of these services is to support road charging through Electronic Fee Collection; to inform drivers about predicted costs;
- International service continuity – an exchange network between neighbouring control centres to ensure continuity of service for travellers;
- Estimated Journey Time – to calculate and inform drivers about the estimated journey time;
- Recommended next link – to recommend an alternative link in special situations/scenarios;
- Map information check to inform of current update for digital maps;

Illustration and technical specifications of prototypes of the Automotive PC and the envisaged HMI design is shown in Fig. 4.

4. RPU Robust Positioning Unit

The RPU provides an access to the following data sources: GPS, Gyro (incl. GPS time), Odometer (revolution of all 4 wheels; incl. GPS time).

For the individual sensors the following requirements are posed from the view of the RPU to the properties of the measurements:

GPS module:
- Chip set should be: SiRF, u-blox Antares4 or equivalent sensitivity.
- The PPS output has to be connected.
- The receiver should be able to process EGNOS information.
- Independent determination of the position (triangulation) and the velocity (Doppler shift) information.
- Position determination should be computed in the module of “precise point position” (ppp).
- No smoothing or filtering should be applied inside the GPS module.

CAN bus:
- Provides the velocity of the vehicle in general.
- Provides the distance increments (pulses) of all four wheels (but at least of two non-powered wheels).
- Timestamps synchronous to the GPS-clock and with a time accuracy of better than 10 ms.
- Signals for the driving direction (forward and backward).
- Sampling rate of 100Hz.
- Resolution of 8 Bit per wheel revolution.
- Measurement range of 50-150 grad/sec.
- Sampling rate of 100Hz.
- Resolution of 12 Bit.
- Timestamp synchronous to the GPS-clock and with a time accuracy of better than 10 ms.
- Temperature signal for the gyro with a resolution of 0.1 degree.

According to above functionalities presented, the CGW (Communication Gateway) was defined, which receives the following messages, Figure 5:
- Messages from the OBU-II CAN.
- Traffic Control Messages (TPEG-RTM) from the COOPERS Service Centre sent over GSM/GPRS.
- Traffic Control Messages from the Road Side Unit (RSU) by means of IR (interface 3) and CALM M5.
- GPS data (NMEA – GGS and RMC Strings) from interface 5.
5. Test Vehicle Configuration

Figure 6 shows the concept of test vehicle configuration. There are all components mentioned above, which are necessary to provide a road test of presented equipment.

COOPERS Tests will partly be executed as pre-integration tests in the laboratories of Dornier Consulting (In-car network) and Applus+ (Road-side subsystem), and partly they shall be performed as integrated subsystem/system tests at all demonstration sites: these are

- Motorway from Nuremberg via Munich, Kiefersfel-den/Kufstein, Innsbruck, Brenner to Trento with three sections (Bavaria, Austria, Italy)
- Motorway Rotterdam-Antwerp (Netherlands-Belgium)
- City Motorways in Berlin (Germany)
- Secondary roads in the “Region Darmstadt”
- Motorway A7 Vienne-Valence (France)

The demonstration site of the “Region Darmstadt” has the aim to extend the spectrum of road networks for COOPERS. On the example of the COOPERS service S5 “In-vehicle variable speed limit information” it will be demonstrated, how this service can support the driver on secondary roads as well. Therefore this service was translated to the special constraints of secondary roads and is described as the service S5a “Adaptive speed limit warning and curve warning on secondary roads”. The second focus of the demonstration in “Region Darmstadt” is motivated with the integration of Galileo for COOPERS’s services. For the COOPERS project the objective of robust positioning is of main interest for the European Commission and especially the potential contribution of Galileo to support the selected services. Therefore a unique approach has been designed to test the benefits of Galileo within the application, before the space segment of Galileo has been installed.

For the evaluation of the results from executed test trials, it is necessary to know the true trajectory or at least a very accurate and reliable estimate of it. Therefore, The Technical University of Lodz (LOD) has combined a high precision inertial measurement unit (IMU), which was aided through an external wheel pulse transducer (WPT) with high resolution and dual frequency GPS receiver. The measurements are recorded in parallel but strictly independent to the other system of the COOPERS OBU and the scientific development platform inside the PWP concept car.

The modules of reference systems can be found in three locations, a special dual frequency antenna with advanced reception characteristic on the roof, the Corrsys Datron WPT at the outside of the back wheel and the additional reference sensors including a recording laptop in the trunk of the vehicle. While the reference system does require the most installation space, the modules of the COOPERS OBU are rather small in size and have all been installed in the cabin of the vehicle. The assessment of technical performance of RPU will be executed by the LOD as a neutral instance for this task. In order to qualify the remaining error behaviour of the RPU by measurements, hard facts will be generated for the process of the technical assessment. The applied hardware components of Corrsys, IMU, and dual frequency GPS are very costly (more than 50 000 EUR) and do not qualify for an economic solution with respect to the task of robust positioning with COOPERS.

For the correct and precise determination of the performance of RPU during kinematic test trials with the concept car a reference system is necessary that operates at the same time reference as the RPU. For this task SPAN system (Synchronized Position Attitude Navigation) has been applied by the TU of Lodz. While the SPAN operates on the basis of GPS time, most low-cost GPS receivers provide the UTC time. The timing accuracy in both systems is sufficient, but by definition there exists a time drift between the GPS time and UTC, which is currently determined with 15 lead seconds, that have to be compensated to achieve proper synchronization. The core of the SPAN system is an inertial measurement unit (IMU), which consist of fibre optic gyros (FOG) and three precise accelerometers. This sensor assembly can perceive the rotation and translation motion of the vehicle in all three axes, to cover the complete six degrees of freedom with respect to physical motion.

The measurements of all reference sensors are logged via the software tool from the SPAN unit, which is running on a separate laptop from LOD. The interface of the SPAN systems is kept quite simple and allows controlling
the proper operation of the reference equipment during the test ride. In comparison to the RPU, the SPAN system has a quite long procedure for initialization, until all the single sensors are calibrated. The HMI of the SPAN has a similar view of cockpit instrumentation, which comes from the fact that costly equipment is used for aviation, rather than for land transport. This shows a high reliability that comes with the inertial sensor systems and proves again that a high effort is appropriate, in order to generate a reliable reference trajectory for robust positioning applications like the COOPERS-services.

5. Simulator study

A driving simulator is a complex tool that can be used for many different kinds of purposes. Typically it can be used for vehicle dynamics studies, driver behaviour studies, road design and visualization, man-machine interaction studies, virtual prototyping of vehicles and vehicle systems. The VTI built its first driving simulator already in 1975, and has since then performed studies within all of the mentioned categories.

A main part of the overall COOPERS project deals with problems concerning the data transmission (in its broadest sense). In contrast, it was decided that the driving simulator study would deal only with traffic safety issues. It was also decided that most benefits from this study would be achieved with a study of driver behaviour, comparing driving with the COOPERS onboard unit as opposed to driving without the COOPERS onboard unit. The comparison would be made in situations that could not be achieved in the upcoming field studies. Thus, the simulator study should be regarded as a study that is complementary to the field studies, with the purpose of retrieving information that otherwise could not be obtained. The simulator study should not be considered as a virtual test bed for developing the field study methodology or the HMI of the COOPERS onboard unit. However, since the driving simulator test would be carried out before the field tests, many results would be useful for the field tests at the demonstration sites, e.g. the design of the user acceptance questionnaires. And, although the simulator study was not designed with the purpose of developing the HMI design of the COOPERS system, the feedback from the drivers that took part in the simulator study may also lead to improvements in the HMI before the tests at the demonstration sites would be performed. The driving simulator study was carried out at the VTI using 48 Swedish test drivers, 24 men and 24 women. The drivers had to drive 40 km Swedish motorway without, and 40 km with the COOPERS system, while being exposed to some critical, and some not so critical events. These events, denoted scenarios, were chosen with the COOPERS services in mind. Some of the scenarios were chosen specifically for the simulator study since they were too rare or too critical to be achieved in real traffic driving in the upcoming COOPERS field test. Objective measures on driver behaviour were sampled, e.g. the speed and vehicle position on the road, including the eye movement pattern of the drivers. Physiological measures such as the ECG and skin conductance were recorded for evaluation of the driver’s stress level. The driver’s subjective experience from driving with the system and their perceived stress during the scenarios was also captured. Furthermore, an acceptance study was carried out, which will be reported elsewhere.

The primary aim of the study was to measure and compare driver’s behaviour when driving with the COOPERS system as opposed to driving without the COOPERS system. The driving behaviour was supposed to be studied in situations where a traffic safety problem might occur. Apart from the primary aim, the simulator study also enables the study of driver behaviour during more general motorway driving.

The four scenarios involved were created to include some of the COOPERS services earlier defined;
- “Congestion” - The driver approaches a sudden congestion that is standing still.
- “Fog” - The driver has to pass a 1 km long road section with heavy fog.
- “Ambulance” - An ambulance approaches the driver at high speed from behind and needs to pass.
- “Ghost driver” - The driver meets a vehicle driving in the opposite direction in his lane on the motorway.

The results of the present study show that when the system is active, the drivers adapt to the scenarios according to the information given through the system. For the congestion and the fog, the drivers lower their speed after having received a warning about the upcoming situation. The ambulance scenario showed a decrease in longitudinal acceleration and the time to collision in the ghost driver scenario was decreased when a warning had been issued through the system. This indicates that even for traffic events that are critical, the driver has an advantage by the system warning and has time and opportunity to adapt to the situation, hence creating a safer scenario.

All changes in drivers’ behaviour that were found in the simulator study can be considered beneficiary from a traffic safety perspective. Other possible benefits from a COOPERS-like system would be that the driver has an opportunity to better plan his route according to the circumstances on the road. If the driver receives information on upcoming traffic delays well ahead, he/she can choose a different route to avoid for example congestions or bad weather, hence making the overall traffic situation better.
6. Conclusion

Coopers project using OBU:
- Focuses on services and driver's behaviour/user acceptance.
- Influences significantly driver's behaviour.
- Influences driver's behaviour positively.
- Is accepted by all drivers independent of the acceptance level.
- People are willing to pay for it.

An open system of ITS architecture and the OBU presented enables new features and standards of vehicle use. There is no problem to add another service, so called low emission; the next steps of authors will be focused on a low fuel consumption.

Bibliography