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Human-Machine Interaction in Automated Vehicle : The ABV Project ⋆

Chouki Sentouh, Jean-Christophe Popieul, Serge Debernard * **Serge Boverie** **

* *Laboratory of Industrial and Human Automation, Mechanics and Computer Science, LAMIH - CNRS UMR 8201, University of Valenciennes, Mont Houy- F-59313 Valenciennes, France (chouki.sentouh@univ-valenciennes.fr, Jean-Christophe.Popieul@univ-valenciennes.fr, Serge.Debernard@univ-valenciennes.fr).*
** *Continental Automotive SAS France, Department of Advanced Development for Safety Applications, Toulouse, France (serge.boverie@continental-corporation.com)*

Abstract: The work described in this paper is part of a research program named ABV (Low Speed Automation) where the goal is the automation of road vehicle at low speed while ensuring the sharing of driving between the driver and the assistance. This paper focuses on the problem of human-machine cooperation in the specific context of vehicle driving, with a view of shared control between driver and automation, considering the acceptability of the system and the driver distractions and drowsiness.

Keywords: Shared control, human-machine cooperation, active safety, driver-vehicle interaction, lane keeping assist system.

1. INTRODUCTION

ADAS have been studied since the early 90s, and now they are largely established in automobiles. The goal of these systems is to improve the controllability of the vehicle, warn the driver well in advance on a situation where he must intervene and make the vehicle capable of providing the driver a considerable aid to navigation as well as to the task of lane keeping (AEB [1] , LKS [2] ,...).

The human-machine cooperation is a challenging problem since the introduction of automated systems in the various fields of human activity, especially in the aviation field [Parasuraman et al. (2000), Hoc (2001)]. In road vehicle driving, this problem is relatively recent, its appearance follows the initial works on driver assistance in the late 80s (PATH in USA and PROMETHEUS in Europe). Thus, from the 90s considerable work has been carried out to address this issue [Nagel et al. (1995)].

According to Piaget (1977) : "Cooperate in action is to operate in common, that is to say, adjust with new operations, the operations performed by each partner, it's coordinate the operations of each partner in a single operating system in which the acts themselves of collaboration constitute the integral operations". This leads us to the following questions [Hoc (2001)] :

- When to intervene to assist the driver?
- How to do it and at what degree?
- What the effect will this intervention on the driver?
- Finally, whom assign responsibility for the driving?

Sheridan (1992) gives the definition of "Sharing control" where the human operator and machine work together, simultaneously, to make or perform a task. He also defines "Trading control" as an alternate control where one of the two agents is responsible of a function, and either the human operator or the machine performs the function from time to time (a change of active agent).

Many experiments were carried out to the general public on the full automation of driving, including presentations of the Google Driverless Car [Google (2010)], and VisLab Driverless Car [VisLab (2013)]. Most of these experiments aim the full automation, where the driver is completely out of the driving task. However, future generations of driver assistance systems must be developed to ensure a smooth action of the controller continuously while keeping the driver in-the-loop without generating negative interference [Hoc et al. (2006), Bainbridge (1983)]. This was particularly highlighted in national and international projects as PARTAGE (2009-2013) and HAVEit (2008-2011). These projects and academic research cited above have demonstrated the need to integrate, in the design process of the system, the problem of interaction with the driver by resolving problems of task sharing and degree

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[1] Automatic Emergency Braking
[2] Lane keeping System

of freedom, authority, level of automation and Human-Machine Interface (HMI).

The ABV project has focused on the interaction between human and machine with a continuous sharing of driving, considering the acceptability of the assistance and driver distractions and drowsiness [Boverie et al. (2008)]. The main motivation of this project is the fact that in many situations, the driver is required to drive his vehicle at a speed less than $50km/h$ (speed limit in urban areas) or in the case of a traffic congestion due to traffic jams, in the surrounding of big cities, for example.

In this paper we present the specification of cooperation principles between the driver and the assistance system for lane keeping developed in the framework of the ABV project (Low Speed Automation). Within this project, the LAMIH piloted in partnership with CONTINENTAL Automotive the task of "Human-Machine Cooperation (HMC) and Driver Monitoring (DM)" which was intended to define, prototype and evaluate the interactions between the ABV system and the human driver.

2. THE ABV PROJECT

2.1 Objectives

Some assistance systems act during critical driving situation to correct the vehicle trajectory (e.g. ESP), such as solutions developed by automakers in terms of active safety. Other driver assistance systems operate most upstream as for example continuous shared control mode where the controller provides a partial steering control action. The ABV project aimed the design of an automated vehicle at low speed while ensuring the sharing of driving with the human driver. Thus, the project has addressed the problem to integrate the lateral and longitudinal control functions of the vehicle considering the driver-in-the-loop. The task 4 of the ABV project (see Figure 1) addressed the cooperation between the human driver and the assistance system in a perspective of shared control between driver and automation, considering the distraction, inattentiveness and fatigue of the driver.

The ABV project is a research project funded by the National Research Agency. It associated four industrial players (Continental, Viametris, Induct and VERI) and six academic actors (IFSTTAR, IBISC, IEF, INRIA, LAMIH and MIPS). GMConseil has attended the IFSTTAR to study the legal aspects. The project began in October 2009 for a period of 42 months.

2.2 Structure of the ABV project

The ABV project is divided into nine tasks articulated as we can see in Figure 1. Tasks 1 to 4, which are the perception of the environment, the path planning, the vehicle control and the interaction with the driver, aimed scientific developments of automation. Tasks 5 to 7 dealt with the integration in vehicles and validation. Tasks 8 to 9 addressed the problem of the societal impact of systems developed in the framework of the ABV project.

In this paper, we describe the work carried out under the task 4 of ABV "Human-Machine Cooperation and Driver Monitoring". The problem addressed in this task is related to the human-machine cooperation and more specifically the dynamic allocation of tasks. The object is to determine whom assign at each time any part of the vehicle control according to the driving situation (operating range), wishes of the driver but also criteria related to his capacities (Driver Monitoring) and naturally based on criteria related to capacities of the machine (level of automation). This task required the development of specific human-machine interfaces (HMI).

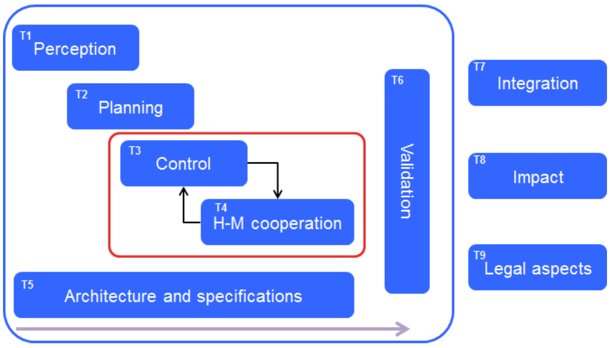

Fig. 1. Structure of the ABV project

3. SPECIFICATIONS OF THE HUMAN-MACHINE COOPERATION

This section details the specifications of the cooperation principles between the driver and the ABV system.

3.1 Operating modes of the ABV system

The state graph of Figure 2 shows the different modes of the ABV system and the conditions which allow to change from one mode to another. So, this figure describes all the features available and how to pass from one mode to another depending on the situations encountered and the actions of the driver. Therefore, this graph defines first, the level of automation of the overall human machine system; then it defines the management authority between driver and controllers: who is in charge to modify the level of automation. Conditions of mode change depend on different factors: technical factors as controllers competencies, driving situations, but also human factors as loss of vigilance or attention. Except when the system is off, four main modes have been defined (yellow bubbles in Figure 2) :

- In the first one, the driver performs alone the driving task : this is the MANUAL mode. Nevertheless, in this mode the Driver Monitoring is active and can produce an alert.
- In the second mode called SCOUT, the controller performs alone the overall driving task : lateral and longitudinal control. This mode is available when the vehicle speed lower than $50km/h$ and only on secured path : all the information needed to run the ABV system is, in this case, available for this route (GPS cartography, road marking, etc.). This implies that locations where secured path begins and ends are known, as well as areas where emergency lane are available. In this mode, the vehicle is autonomous but the human driver can intervene at any time on

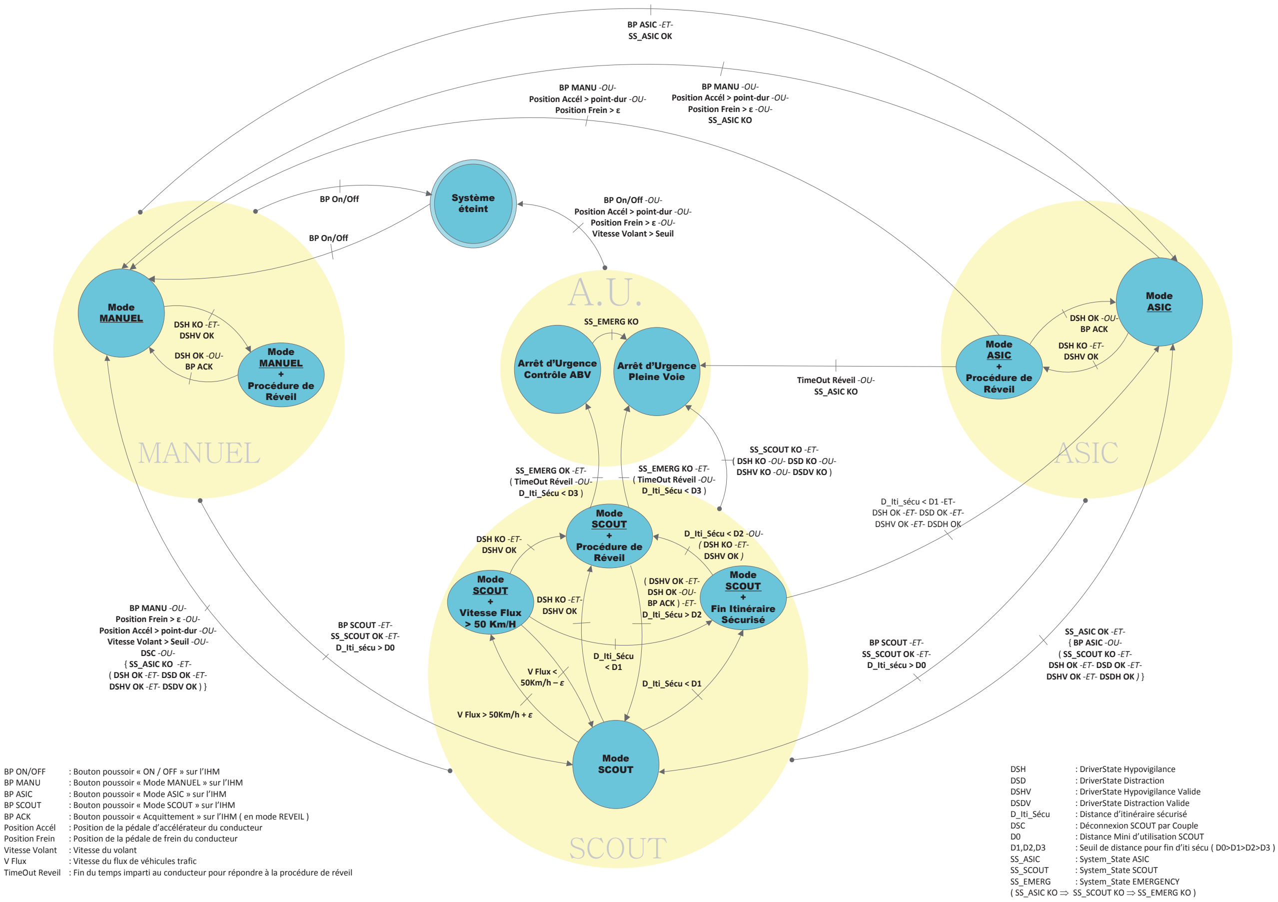

Fig. 2. Graph of the different modes of the ABV system

the wheel : the driving task is then shared with the controller.

- In the third mode called ASIC, the controller performs only the longitudinal task : the controller operates in both speed control and regulation of inter-distance from the vehicle ahead in accordance with driver instructions and rules of the Highway Code. This mode can be used on normal roads, but also on secured path. In this case, it allows a reduction in the fuel consumption based on a more accurate knowledge of traffic and the geometry of the path ahead.
- The last mode is an emergency shutdown (AU) which preserve the safety of the vehicle and its passengers, by stopping it in an automatic manner.

In each of these four modes, different sub modes have been defined. The transitions from one sub mode to another one are represented by arcs with a transition and the corresponding receptivity (see Figure 2). The latter represents a Boolean equation having various elements such as an action on the interface (e.g. BP_{SCOUT}), a parameter related to the vehicle (e.g. speed), a parameter related to the situation (e.g. end secured path), a parameter related to the driver (e.g. drowsiness) or finally a controller state (e.g. system SCOUT OK).

3.2 ABV System HMI

The HMI shall allow the driver to monitor the ABV system. This supervision, therefore the activities of monitoring and control which result from this, must in particular enable the driver to maintain his conscience of the operating mode. Indeed, if the driver can modify the level of automation of the human-machine system (driver-ABV system) by delegating a part or the totality of the driving activity to the ABV system. This system has also the possibility to give back to the driver what has been initially delegated. It is thus absolutely necessary that the driver knows at any moment "who is in charge of what"!
During the use of a particular operating mode of ABV, it is also necessary that the driver, on the one hand "understands" what the system does, and on the other hand, that he can also monitor it. The carried out work led us to design the interfaces meet to these major requirements, but also by taking into account the characteristics of the driving activity which can require to communicate with the system while ensuring the visual monitoring of the traffic and infrastructure. This HMI uses three different interaction modalities, sound, visual and haptic.

The HMI of the ABV system is composed of various elements :

- A touch screen that allows the driver to activate the different operating modes and which provides information feedback.
- The steering wheel, equipped with a torque sensor, is an essential part of the ABV HMI. It allows the driver "to feel" the operation of the system (e.g. when keeping lane center) while allowing the

Fig. 3. The touch screen of the ABV HMI

lane changes or the obstacle avoidances via a haptic communication.
- The "haptic" accelerator pedal can also provide feedback information to the driver about the management of the vehicle speed.
- The sound feedback generator.

From the point of view of the driver, ABV system manages two "components" of the trajectory : the speed and the position of the vehicle with respect to the infrastructure and the other vehicles. The interface must give information related to these two "components". The choice that was made to share the interface between two main information areas (Figure 3) :

- a left upper part that displays information about the control of the vehicle speed is a conventional tachometer to which were associated symbols/codes of colors bringing additional information like the activity of the force feedback accelerator pedal, the speed limit of the road section, the fact that speed respects the constraints of the SCOUT mode when this one is engaged, etc. The left lower part of this area is restricted for the text messages.
- a right part displaying information relating to the lateral control and management of the interdistance. The selected design represents the position of the vehicle in pseudo 3D, taking its inspiration in the interfaces currently used on ACC or navigation systems.

3.3 Driver Monitoring

The Driver Monitoring (see Figure 4) is used in the different operating modes :

- In ABV SCOUT mode, to verify that the driver is currently watching to the road, even if he is not actively involved in the driving activity. In the case where the state of the DM is not OK, the alarm process is activated.
- In ABV ASIC mode, to verify that the driver is currently watching to the road. The lane keeping performance is also determined. In the case where the state of the DM is OK but the lane keeping performance is not OK, the alarm process is activated.
- When changing the operating mode (e.g. from Automatic to Manual), to verify that the driver is able to regain control of the vehicle before disconnecting the Automatic mode. In the event that the driver does not react to the alarm process, the emergency stop procedure (AU) is activated.

In the first two cases, the DM is equivalent to a "deadman" security system. In the latter case, the DM may be coupled with a system to detect that the driver has at least one hand on the steering wheel.

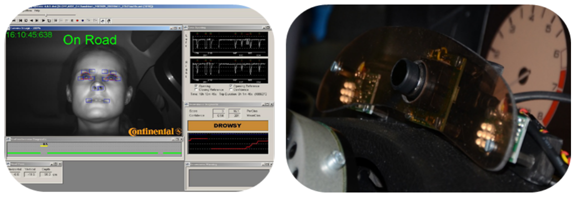

Fig. 4. 'Driver Monitoring' system from Continental

4. COOPERATION REALIZATION

This part deals with the identification of all the problems which could affect the safety or the correct operation of the system, especially with the level of the interaction with the driver and the driver monitoring in the transient stages between operating modes.

4.1 Mechanisms for operating modes switching

This part details the mechanisms of switching between the operating modes of the ABV system. Switching can be at the initiative of the driver or of the system itself, according to various types of situation. These mechanisms integrate in particular the use of the Driver Monitoring which insures that the driver is able to take again control of the vehicle when a mandatory switching from an automatic mode to the manual mode is required, or to make sure that the driver is not drowsy and he is aware about the situation. The various parameters used as conditions for transition between states are presented below :

- Pushbuttons that allow to set on and off the ABV system and to switch manually from one operating mode to an other, to acknowledge an alarm triggered by an hypovigilance or distraction detection coming from the driver monitoring and ends the emergency "awaking" procedure.
- Four information coming from the driver monitoring are used to manage the various operating modes. Information DSH (Driver State Hypovigilance) indicates either that there is a problem of vigilance of driver (DSH KO), or not (DSH OK). This information must be validated by DSHV (DSHV OK - Driver State Hypovigilance Valid). If information is not valid (DSHV KO), DSH cannot be taken into account. Information DSD (Driver State Distraction) indicates that the driver is inattentive (DSD KO) or not (DSD OK). As above, this information must be validated by information DSDV (Driver State Distraction Valid).
- Flags SS_{ASIC}, SS_{SCOUT} and SS_{EMERG} indicate that the system runs correctly (OK) or not (KO). The first two indicate that the corresponding operating modes run correctly, whereas the third indicates that a trajectory leading to the emergency lane is available to carry out an emergency stop. It should be noted that if the ASIC mode is not available, modes SCOUT and Emergency Stop are not available either, mode ASIC being a subset of the two others. In the same

way, if mode SCOUT is not available, the emergency stop mode is not available either.
- Flag DSC (Scout Deactivation by Torque) indicates that the driver applied an important torque on the steering wheel that exceeds the limits set by the system (depending on the situation). In that case, the automatic driving mode is deactivated. In a same way, the steering wheel angular speed denotes a very fast action of the driver when it crosses an experimentally fixed threshold. In that case, the operating mode is also modified.
- Information "Brake Position" and "Accel Position" indicate that the driver respectively operates the acceleration and footbrake pedals. For the brake, exceeding a given threshold causes the deactivation of the activated automatic mode (SCOUT or ASIC). For the accelerator, the driver must exceed a hard point programmed in the active pedal so that the deactivation occurs.

4.2 Shared control architecture

As already mentioned above, in SCOUT mode the driving assistance is in charge of the lateral and longitudinal control but the driver can intervene at any time on the wheel. The driving task is currently shared between the assistance system and the driver. Figure 5 summarizes the architecture of the shared lateral control.

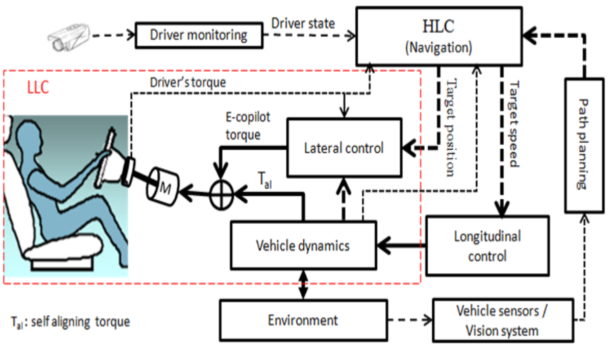

Fig. 5. Shared Driving Control architecture

Two levels of cooperation have been identified to ensure better sharing of control.

- A Low-Level of Cooperation (LLC) which occurs at the operational activity level. LLC is concerned with cooperation in action, where the driver interacts with the system, directly on the steering wheel. This level of cooperation includes the detection and resolution of interferences in order to avoid any conflict. The automatic control acting on the steering system can be seen as a disturbance by the driver as well as the effect of the control actions of the driver by the assistance. Therefore, these elements are taken into account in the controller design to minimize negative interactions (conflict) between the assistance and the driver. We will consider later that a conflict is characterized by reverse torques applied simultaneously on the steering wheel by the driver and the assistance.
- A High Level of Cooperation (HLC) which occurs at a strategic activity level for planning cooperation. This level of cooperation is more concerned by the choice of paths to follow, taking into account the state of the driver (steering torque and information from Driver Monitoring - DM) and the current driving environment situation.

5. RESULTS

Here we present only the results of the work aiming to provide a solution to conflicts at LLC level that can be generated when the driver and controller act together (at the same time) on the steering wheel for lateral control. This is the case for example of a driver that optimizes the path when negotiating a curve or deviates from the planned path to avoid an obstacle that would not have been detected by the perception system.

We consider, in this case, only one valid path proposed by the path planning unit. To allow the sharing of control between the driver and the controller directly on the steering wheel, the steering torque control was privileged according to Shimakage et al. (2002). An approach based on optimal control theory incorporating a driver model in the design process of the controller, proposed in Sentouh et al. (2010, 2013), has been used. The idea is to integrate the driver torque in the state vector of the system in order to take into account, in the performance vector, the conflict between the driver and the controller. The controller will have the task of assisting the driver in performing the lane keeping task while minimizing negative interferences (minimization of conflict).

Results of experimental tests performed on the SHERPA simulator (interactive simulation) present a comparison of two controllers : a first controller synthesized by integrating a driver model (WDM) and another synthesized using only a vehicle model (OVM). The test scenario is a shared driving in the first curve ($t < 10s$, see Figure 6), then the driver releases the steering wheel and the vehicle control becomes full automatic. The driver must regain control on the steering wheel without deactivating the system to avoid three obstacles in the way.

Figure 6 shows the results achieved on the SHERPA simulator using both WDM and OVM controllers as developed in Sentouh et al. (2013). This figure illustrates the contribution of the driver model in the design of shared lateral control. This has reduced the effort provided by the driver to perform his obstacles avoidance maneuver while remaining in automatic mode.

To assess the quality of control sharing, an indicator of the physical workload associated to the steering effort, taking into account the efforts provided by the driver and the assistance and the steering rate, is used :

$$W_s = \int_0^T T_d(t)\, T_a(t)\, \dot{\delta}_d(t)\, dt$$

where T_d represents the driver torque, T_a is the assistance torque and $\dot{\delta}_d$ is the steering rate. We define the positive and negative interference at the steering wheel, respectively W_s^+ and W_s^- when the product $T_d(t).T_a(t).\dot{\delta}_d(t)$ is positive or negative. The ratio of the steering workload is computed by $R_w = -\frac{W_s^-}{W_s^+}$. The evaluation results of the steering workload W_s obtained using WDM and OVM

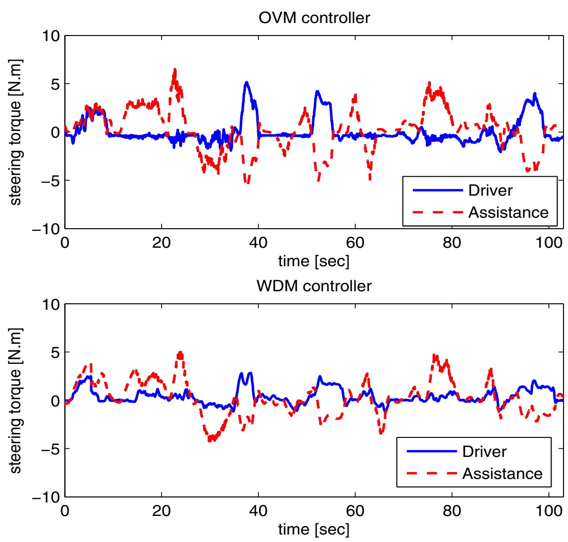

Fig. 6. Experimental results on the SHERPA simulator

controllers are shown in Figure 7. Figure 7 shows that

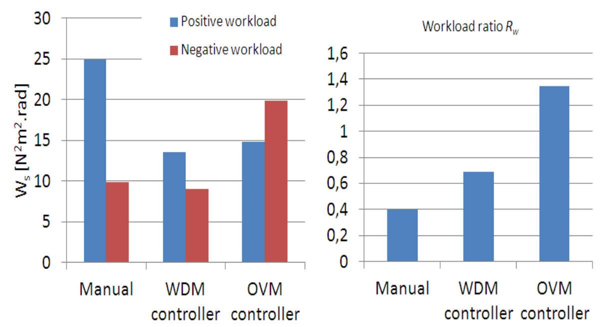

Fig. 7. Evaluation of the sharing quality

the integration of a driver model in the design process of the assistance (WDM controller) can significantly reduce the negative interference ($9N^2.m^2.rad$), in comparison with the OVM controller. The comparison of the steering workload ratio for both controllers is shown in Figure 7-b. The lowest ratio $R_w = 0.7$ is obtained using the WDM controller. The controller designed without driver model (OVM) generates more negative interference ($20N^2.m^2.rad$) than the positive one ($15N^2.m^2.rad$) with a ratio of 1.3.

6. CONCLUSION

In this paper, we presented technical specifications of cooperation principles between human driver and ADAS in the framework of ABV project. This controller cooperates with the driver in order to keep the vehicle in the lane. In this context, three nominal modes have been defined, as well as an emergency shutdown mode. The criteria and the procedures for changing these operating modes were also presented. We also described the architecture used to achieve the lateral shared control between driver and the controller used in the SCOUT mode. The results of tests performed in order to develop the controller are conclusive.

The tests must now be pursued in order to take into account more situations in which cooperation issues and/or conflict between human driver and technical controller appears. These situations will be implemented through interactive simulation on SHERPA, a full-scale driving simulator. The experiments must also involve a larger number of subjects to validate the solutions in terms of their use.

Nevertheless cooperation in planning should enable a better interaction between the driver and the controller in the shared mode. Further work on the shared control will take into account the interactions with the driver in the task of planning trajectory, so at the strategic level of driving activity. This level of cooperation will allow to change the choice of lane to follow, by taking into account the action and the state of the driver (steering torque and information from Driver Monitoring) and the state of the driving environment (other vehicles for instance).

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