Lateral Control Support for Car Drivers: a Human-Machine Cooperation Approach

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ABSTRACT

Motivation – This paper is based on a research project which examines the way car drivers and automated devices cooperate to achieve lateral control of a vehicle. A theoretical classification of automotive devices in terms of human-machine cooperation is presented. Mutual control and function delegation modes are specifically investigated in three experimental studies.

Research approach – All three experiments were conducted using a driving simulator. Driver behaviour was studied under normal driving conditions and in critical situations, with or without the intervention of assistance devices designed to improve lateral control. A new way to help drivers when lane departure was imminent, called motor priming was the main focus of the project up till now.

Findings/Design – Initial results suggest that a motor priming device (asymmetric steering wheel vibrations) is more effective than more traditional warning devices. Preliminary findings also suggest that some negative behavioural adaptation occurs when a car's lateral position is fully controlled.

Research limitations/Implications – Our findings were very encouraging for the future development of in-car automation using motor priming devices. However, before any such application can go ahead, it will be necessary to carry out further experiments, using real traffic conditions and more complex scenarios.

Take away message – Support systems for steering control should be designed in such a way that their action blends into drivers' perceptual and motor processes. Acting at the symbolic level may not be sufficient.

Keywords

Human-machine cooperation, driving assistance device, lane warning departure, motor priming, active steering

INTRODUCTION

Automation is being used more and more in cars today. Car manufacturers use automated devices in order to assist drivers in a large variety of tasks that they have to perform. Human-machine cooperation comes into play when the driver and the automated device interfere when performing their functions (Hoc, 2001). This interference is expected to be positive, that is to say beneficial for the task result compared with the same situation without the automated device. However undesirable negative interference can appears with the introduction of an automated device. The elaboration and maintenance of a COmmon Frame Of Reference (COFOR) between human and machine play a major role in their cooperation. COFOR does not only integrate symbolic information but also subsymbolic information such as sensations at the level of sensorimotor control. Car drivers have to carry out numerous tasks including environment perception, steering control and interactions with others road-users. Consequently the whole activity can not be automated and drivers are at the centre of this complex situation.

Driving assistance classification system

Many types of driving assistance devices are currently available, each addressing different issues related to human-machine cooperation. Hoc and Blosseville (2003) put forward a four-mode classification scheme in order to categorize these driving assistance devices and to discuss related cooperation issues. These classes include a wide range of devices, ranging from those which do not intervene directly into car control to those which fully control the car.

The first mode in this classification scheme is called the perception mode. Devices within this category can be best described as an extension of the sensorial organs. A visual enhancement of the distance between the piloted vehicle and a followed vehicle is a good example.

The second mode is referred to as the mutual control category. For this cooperation mode, drivers perform a given task and the assistance device virtually carries out the same task in parallel. If differences arise between the assistance device action decision and the driver's actions, then the device warms the driver. For example, a lateral control device may use a sound that is triggered when drivers are too close to the lane edge.

The third mode corresponds to function delegation. Here, a task that is usually carried out by the driver is passed to the driving assistance device. Adaptive Cruise

Control is a good example. In this mode, the device adjusts the vehicle's speed within the driving context. For instance, if the car is too close to the vehicle in front, then the driving assistance device reduces vehicle speed.
Finally, it is possible to have a fully automated mode. In this case, drivers only supervise the driving assistance device.
This paper examines lateral control assistance in car driving, focusing on the mutual control and delegation function modes of cooperation.

MUTUAL CONTROL MODES

When applied to lateral control, mutual control can be subdivided into two main parts: LDWS (Lane Departure Warning Systems) and the LKAS (Lane Keeping Assistance Systems). LDWS provide a warning when the car is about to leave its lane (e.g., a sound or a steering wheel vibration). They are devoted to improving situation diagnosis. LKAS partially contribute to steering by applying some torque on the steering wheel in order to bring the car back into the lane. They directly intervene at the action level and are designed to blend with the driver's sensorimotor control processes (Griffiths & Gillespie, 2005). Our research investigates a new way of prompting drivers to take action via haptic modality. This type of assistance is called motor priming and can be described as a directional stimulation of the hands through an asymmetric vibration of the wheel. More precisely, the wheel oscillates, with one direction of the oscillation being stronger than the other. This gives the impression that the wheel vibrates and "pushes" lightly in the direction where the corrective manoeuvre must be performed. This is not an LKAS proper, in the sense that its contribution to steering is minimal, but it does provide some motor priming in addition to warning. Thus, it can be considered as a driving assistance at the boundary between LDWS and LKAS. Our main objective was to determine whether it was possible to observe some benefit from motor priming compared to more traditional auditory or vibratory warning devices. If so, then it was necessary to ask why this was possible.

Experiment 1

Method

This experiment was carried out on a fixed-base simulator (Sim², developed by INRETS-MSIS), using a model of a test track (two-lane main road, about 3.4 km in length; see Fig.3). Five driving assistance devices were assessed. All devices came into play when the centre of the vehicle deviated more than 80 cm from the lane centre. They remained active as long as the car was not driven back under this threshold (Fig.1).
The *auditory warning mode* (AW) was a sound similar to a rumble strip noise emitted in the direction of lane departure.
The *vibratory warning mode* (VW) was generated by a regular rectangular oscillation of the steering wheel.
The *motor priming mode* (MP) was generated by asymmetrical triangular oscillations on the steering wheel.
The *auditory and vibratory warning mode* (AVW) was a combination of AW and VW.
The *auditory and motor priming mode* (AMP) was a combination of AW and MP.
Critical situations were introduced using visual occlusions. At a given point (see Fig. 3 for location of these points), the visual scene was blanked out. This caused the car to move towards the lane edge. When the car was about to leave its lane, the visual occlusion was removed and drivers then had to correct their trajectory.

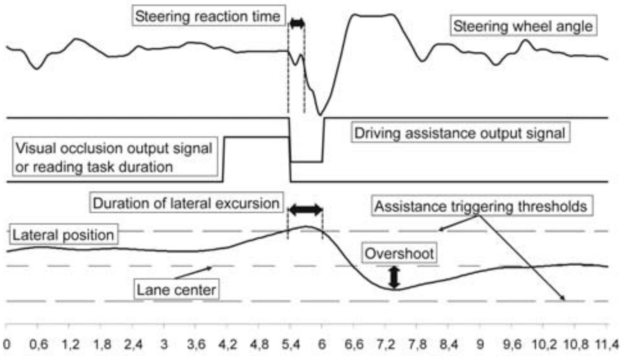

Figure 1: *An example of the sequence of events and results computed for a critical situation for experiments 1 and 2. Drivers were moving forward in their lane when an event (a visual occlusion in experiment 1 or a reading task in Experiment 2), combined with a slight shift in direction of heading, led to a lane departure on the desired side. Duration of lateral excursion corresponded to the time spent by drivers outside the safety envelope of ±80 cm from the midline. Steering reaction time was the time elapsed between the assistance triggering threshold and the drivers' steering wheel response. Overshoot was the distance between the lane centre and the lane borderline on the opposite side to lane departure. Finally, maximum rate of steering wheel acceleration was computed when drivers turned the steering wheel in order to bring the car back into a safe position in the lane.*

Results and discussion

Analyses show that each device significantly reduced the duration of lateral excursion (DLE) compared to the Without Assistance (WA) condition (Fig. 2). This reduction was similar for AW, VW and AVW (warning modes). MP and AMP gave similar results, showing greater reduction of the DLE when compared to the warning modes. Others dependant variables provide results that are going in the same direction than those observed for the main variable (DLE).
See Navarro et al. (in press) for more in-depth information about this experiment.

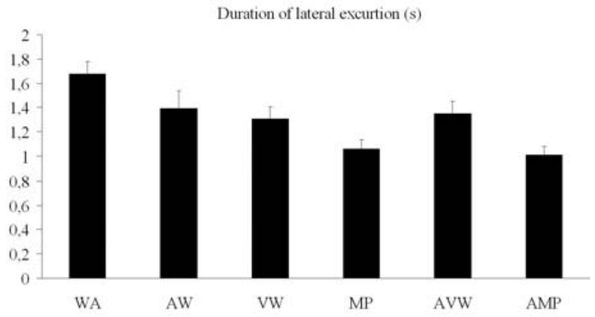

Figure 2: *Duration of lateral excursion for the control condition (WA) and for each device assessed.*

Our results for the mutual control mode show that the use of motor priming assistance significantly improved steering during a recovery manoeuvre in comparison with warning-only assistance devices. This was the case whether they were used alone or in combination with auditory warning assistance. This finding supports the hypothesis that a direct intervention into the sensorimotor control processes (at the action level) can help steering in a lane departure situation more efficiently than a simple warning, which can only improve situation diagnosis. All warning devices (AW, VW and AVW) gave similar reductions of lateral excursion although VW assistance did not give information about which side lane departure occurred. Moreover, combining both sources of information (AVW) did not reduce the duration of lateral excursion. Drivers most probably acted according to the visual analysis of the driving situation, when vision was recovered. A similar conclusion was formulated by Suzuki and Jansson (2003) in their comparison of monaural and stereo sounds. These authors used a pulse-like steering torque, observing that incorrect steering strategies occurred for those drivers who turned the steering wheel in the opposite direction (i.e., in the direction of lane departure), as if they compensated for the torque generated by the device. The authors interpreted the incorrect motor response as a reaction to a perceived lateral disturbance, such as a gust of side wind. This suggests that the action of the driving assistance did not blend appropriately in the sensorimotor control loop. As a consequence, it was most probably felt as intrusive and produced some counteracting steering behaviour. This was not the case with the MP devices since none of the participants adopted an incorrect strategy.

Experiment 2

Framework

This experiment was mainly designed to provide a deeper understanding of motor priming mechanisms. Experiment 1 showed that MP is more effective than the other warning devices assessed. Any differences can be explained by the fact that warning devices act at the diagnosis level, whereas motor priming directly acts at the action level (cf. discussion on experiment 1). This study divides the MP device into several features in order to better understand why it works more effectively than other devices. There are a number of possible reasons for this greater effectiveness. It may be because it delivers information to the steering wheel, because it gives lateralized information, using haptic modality, or by directly intervening at the action level. It also may be a result of a combination of these elements. The second objective of our work was to determine how drivers perceive the different types of assistance devices. To this end, post-experimental verbal reports were used. The principle behind this method was to reconstruct the situations where lane departures occurred. Finally, the second experiment on mutual control enabled us to carry out assessments of driving assistance devices in more realistic situations.

Method

This experiment was carried out in collaboration with Renault. A moving base simulator (Cards2, developed by Renault) was used, together with computer graphics that were capable of generating a highly realistic automobile operating environment.

As in the first experiment, five driving assistance devices were assessed; the same thresholds and similar experimental procedure were adopted (Fig.1). However, the method used to introduce critical situations was changed: drivers were distracted from the driving task by a secondary task where they had to read words displayed on a screen placed on the dashboard. The same AW, MP and AMP modes used in the first experiment were also used in this study. Two other devices were introduced:

The *steering wheel vibratory warning mode* consisted of a lateralized vibration of the steering wheel on the direction of lane departure (directional stimulation of the hand, but without motor priming effect).

The *seat vibratory warning mode* consisted of a lateralized vibration of the drivers' seat on the direction of lane departure (directional haptic stimulation, not in relation with the effectors of steering).

Data analysis is in progress.

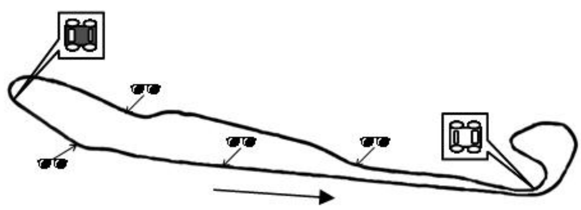

Figure 3: *Layout of the Satory test track. For Experiment 1 (mutual control experiment), dark glasses indicate the points where the visual occlusions were introduced. For the function delegation experiment, black and white cars represent the obstacles to be avoided. The arrow indicates the driving direction.*

FUNCTION DELEGATION MODE

Introduction

This paper also deals with human-machine cooperation when automation is fully in charge of lateral positioning. Drivers still have to manage longitudinal control (vehicle speed) and avoid any potential obstacles on the road. Hoc et al. (2006) observed a negative behavioural adaptation, resulting in drivers having difficulty returning to manual control when the device was invalid (for example, when skirting an obstacle). This adaptation could be related to a negligence of the visual information necessary for lateral control. This study aims first to confirm whether such assistance does result in difficulties during obstacle skirting. If this is found to be the case, then we will determine whether such difficulties are linked to changes in visual scene exploration. Experimental data showed that a particular point on the visual scene (tangent point) is related to the car lateral control (Mars, 2006). Consequently, we can hypothesize that drivers will spend less time regarding this particular point with assistance compared to no assistance condition.

Method

Our third experiment used the same simulator and database graphics as in experiment 1. Gaze position on the visual scene was recorded at a rate of 60 Hz with a head-mounted eye-tracker device (SMI IViewX-HT). Drivers were instructed to drive in the right-hand lane, to keep their hands on the steering wheel, to respect speed limits, and to skirt obstacles if necessary. Drivers had to perform 14 laps of the simulated test track (half of these used automation and half did not). During 4 of these laps drivers had to skirt around a vehicle stopped on the right-hand lane of the road (Fig.3).

Results and discussion

Preliminary results for our third experiment show that, drivers began their skirting manoeuvres later with assistance, compared to the No Assistance condition. They also made a larger steering wheel correction, resulting in a larger lateral gap, and spent more time in the left-hand lane.

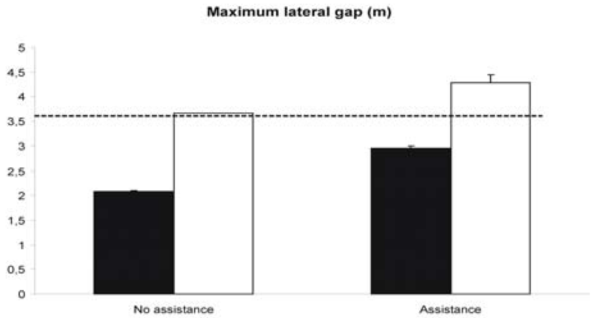

***Figure 4**: Maximum lateral gap on the left-hand lane during obstacle skirting for the two obstacles (see Fig.3). The dotted line represents the edge of the left-hand lane and 0 the road centre.*

Visual strategy analyses are in progress.

Preliminary results strongly support the assumption that negative behavioural adaptation will occur with the introduction of the assistance. This phenomenon may be related to complacency as suggested by Hoc et al. (2006).

FUTURE WORK

As noted by Suzuki and Jansson (2003), and by ourselves during Experiment 1, a warning that indicates the side of lane departure does not appear to be used by drivers. However, laboratory studies looking at stimulus-response compatibility argue for the use of warnings that indicate the side of lane departure. A study specifically designed to clarify this lateralization effect is currently under development.

CONCLUSION

Human-machine cooperation in car driving is a noticeably different situation compared to more classical, mostly symbolic, human-machine activities. Contrary to these activities car driving requires many perceptual and motor control tasks. Our results on mutual control mode show that acting at a symbolic level (warning-only devices) is less effective than acting at both symbolic and drivers' perceptual and motor control processing levels (motor priming devices). Further results on the function delegation mode should allow a better understanding of the combination between symbolic level (complacency) and perceptual and motor control processing level (visual strategies).

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