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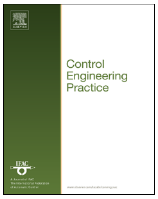

Automation-driver cooperative driving in presence of undetected obstacles

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A B S T R A C T

The work presented in this paper describes and discusses the principles of a haptic shared control between a human driver and an Electronic copilot (E-copilot) for a vehicle. The aim of the sharing control is to allow the driver to momentarily take control over the E-copilot without deactivating it nor being constrained, in order to deal with a specific situation such as avoiding an obstacle that has not been detected by the E-copilot. As the E-copilot acts simultaneously on the steering system with the driver, both have to be aware of one another's actions, which means bi-directional communication is essential. In this work, to achieve this goal, we consider the haptical interactions through the steering wheel. The torque applied by the driver on the steering system is used by the E-copilot to take into account the driver's actions while the E-copilot assistance torque is felt by the driver and used by him to understand the system's behavior. This low communication level strongly improves the cooperation between the driver and the E-copilot.

The system takes into account the drivers actions thanks to a driver lane keeping model that is added to the road vehicle one in the controller synthesis step. This allows to introduce driver's interaction control variables in such a way that the E-copilot can consider conflicting objectives between the driver and the lane keeping task, and thus handle them.

In order to highlight the assets of the approach, a comparison of the behaviors of a simple lane keeping E-copilot to that of a cooperative proposed here is given at the end of this paper. This comparison is achieved through computer simulations and experimental tests with a human driver carried out in the SHERPA-LAMIH interactive dynamic driving simulator. The results of these tests confirm the improvement of the level of cooperation between the human driver and the E-copilot and show that the cooperative E-copilot gives more authority to the human driver especially in hazardous situations.

1. Introduction

Automobiles are essential in our modern society; more than 82% of people (in France) use their cars for their everyday travels. Nevertheless, the car remains a common cause of death and disability (67 288 accidents in 2010 in France causing about 4000 deaths, where in 90% of the cases the driver is responsible, O.N.I.S.R., 2010). A way of proceeding to remedy for this situation is to introduce assistance systems that can help the driver in normal and hazardous situations.

The present technical advancements of automatic control, data processing and telecommunications as well as the reduction in cost of electronic components and their miniaturization, offer the ability to develop Advanced Driver Assistance Systems (ADASs). ADAS can assist the driver in safely navigating the vehicle, which reduces the workload of driving and road accidents (Isermann, 2008; Rajamani, 2006).

Mammar et al. (2005) classified the driver assistance systems into three groups according to their action levels. In the first group there are systems that try to stabilize the vehicle by acting at a low control level so that the vehicle remains more stable and controllable by the driver. This is the case of ABS and ESP that are integrated in most new vehicles. The common feature of such systems is their restriction to only the information (measurements) on the vehicle's state. Second group there are systems that alert the driver if a risk is detected (possible lane crossing: Lane Departure Warning Systems, too close to an obstacle, unadapted speed before a curve, etc.) and no action is being taken to avoid the hazards (Lee, 2002; Sentouh, 2007). These systems can be quite ineffective if the driver is inattentive. This group also includes systems that act if the warning does not have an effect, but exclude

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the driver in the driving process (Enache, Mammar, Netto, & Lusetti, 2010). The last group concerns the systems that can take action and modify the vehicle's dynamics and/or trajectory or those which perform a part of the driving task, like ACC (Adaptive Cruise Control) for longitudinal control.

Several solutions using different control strategies and technics to the lane tracking problem were proposed in the literature in order to cover human errors (El Hajjaji, Ciocan, & Hamad, 2005; Enache et al., 2010; Naranjo, González, García, de Pedro, & Haber, 2005; Netto, Chaib, & Mammar, 2004; Shimakage, Satoh, Uenuma, & Mouri, 2002; Tanaka & Sano, 1995). In Tanaka and Sano (1995) the authors have proposed a Takagi–Sugeno controller that stabilizes a car for a trajectory tracking. Naranjo et al. (2005) have proposed a two layer controller combining a high level fuzzy logic controller with a PID controller at a low level for an autonomous steering car. The proposed controller is implemented and successfully tested within real vehicle.

Most of works dealing with the lateral control (so lane keeping) use the steering angle as a control signal in the framework of autonomous vehicles (El Hajjaji et al., 2005; Naranjo et al., 2005; Netto et al., 2004; Tanaka & Sano, 1995). Through this the driver is neglected in the driving process or his actions are considered as perturbations! But when the system is in a situation that it cannot cope with, full control is restored to the driver. This can generate a serious accident risk because these situations are generally complex (that is why the system cannot handle them) and the driver might not be ready to perform the right maneuver (since he has not had control of the vehicle for a long time, he is certainly not aware of the situation or not attentive to it). So, while the reliability level of autonomous vehicles is not yet sufficient to introduce them to a real environment, an efficient solution is certainly cooperative control. This will keep the driver in the loop in order to sustain his attentiveness level and contribute to a better confidence in the system allowing the driver to handle complex situations in cooperation with the system (Biester, 2005; Flemisch et al., 2003).

Nagai, Mouri, and Raksincharoensak (2003) suggest that a way to allow the driver in the driving process of a vehicle equipped with an E-copilot is the use of the steering torque as a control signal. The authors have made a comparative study between a steering angle control and a steering torque one and suggest that the steering torque control is more appropriate to permit the driver's steering actions. The steering angle control provides good robustness, however, it does not permit the driver's actions during the steering process. It considers them to be disturbances and therefore does not allow them (Shimakage et al., 2002).

The level of cooperation between the driver and an E-copilot can be improved considering the driver in the loop through the integration of a driver (driving process) model to vehicle–road one that allows the integration of *a priori* information about the driver steering behavior (Louay, 2012; Sentouh, Debernard, Popieul, & Vanderhaegen, 2010). Works concerning driver modelling have begun since the 1960s (Pilutti & Ulsoy, 1999; Sentouh, Chevrel, Mars, & Claveau, 2009; Wohl, 1961) but until now few works in driver assistance systems have taken into account the driver in the controller synthesis step. Sentouh et al. (2010) have proposed an approach where the vehicle–road model is augmented with the driver lane following model, and with this, the obtained controller takes into account the driver's actions. To avoid unresolved conflict situations an authority managing algorithm is proposed.

With regards to Human–Machine interaction viewpoint, the introduction of automatic steering in a vehicle with a human driver involves the crucial study of the interaction between the two agents. However up now few works have dealt with this question (Flemisch et al., 2003; Flemisch et al., 2008; Griffiths & Gillespie, 2004; Steele & Gillespie, 2001). One of the efficient means of communication between the automation and the driver is the haptic interface via the steering-wheel (Griffiths & Gillespie, 2004). Flemisch et al. (2003) and after Flemisch et al. (2008) introduce the concept of H-metaphor as a guideline for driver assistance system conception. The authors argue that in the state of technical progress achieved today the full autonomous vehicle is not the best solution. They refer to the image of a rider and his/her horse to inspire the conception of an intelligent vehicle where the interactions between the human driver and his vehicle via the steering system are incorporated in the same manner as those between the rider and his/her horse through the reigns: The horse is able to navigate alone but responds to the rider's commands by use of reigns.

Fig. 1 gives the global shared driving task scheme. The cooperation between the driver and the E-copilot occurs at two levels. The first one is called High Level of Cooperation (HLC). HLC can be seen as the cooperation at the navigation level. The state of the global system (environment–vehicle–driver–automation) is taken into account at this level of processing the information provided by the trajectory planning unit, the driver monitoring unit (driver state), the traffic and the vehicle's state. Depending on the state of each component of the system, decisions are taken to choose the mode in which the system can run: full automatic, cooperative or manual as well as the vehicle trajectory choice. This paper does not deal with this level of cooperation, we only consider the cooperative mode in which the driver and the E-copilot together assume control of the vehicle.

The second level of interaction is called Low Level of Cooperation (LLC). The LLC concerns the interactions between the driver and the E-copilot in the steering system (action). The communication means

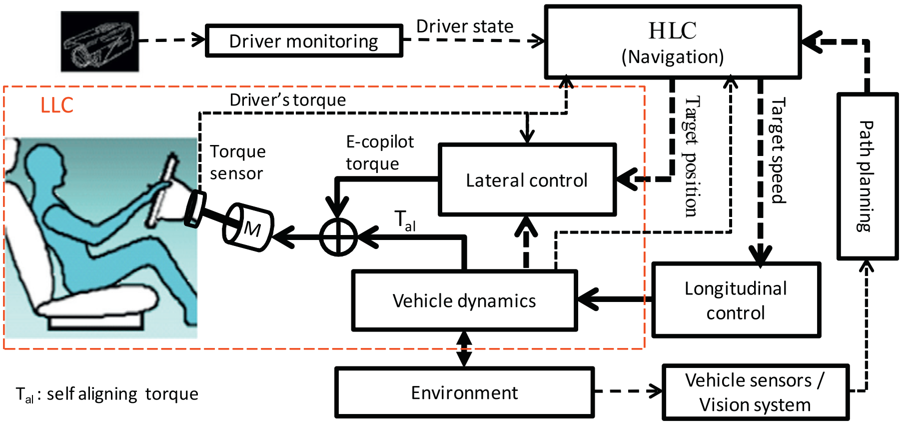

Fig. 1. Global sharing control scheme.