Adaptive Human Machine Interfaces in an Autonomous Vehicle

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Figure 1: AFP Illustration of PS (Passenger-Supervisor)

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Abstract
In this position paper, we focus on human cockpit interaction using a human centered approach, that is to say the identification of important information that might be provided to drivers referring to the different levels of situation-awareness. We tackle the following question: "How to operate a dynamic delegation to the machine in the case of autonomous vehicles?".

Author Keywords
Human-AI interaction and collaboration; Multimodal Interaction and Interaction Design.

CCS Concepts
•Human-centered computing → HCI theory, concepts and models;

Introduction
Recently, autonomous vehicles have become a reality: many current production cars use features that enable better autonomy and driving control. In addition, future predictions foresee a considerable increase of the effective road capacity for autonomous and interconnected vehicles. However, a problem that has fewly been addressed is the interaction mechanisms used to operate a dynamic delegation from the machine to the human and vice versa depending on the context and situation. In this context, it

is important to investigate the field of Explainable Artificial Intelligence (XAI) since interpretability and transparency are key factors for increasing trust and security. In this position paper, we focus on human cockpit interaction, that is to say the identification of important information that might be provided to drivers referring to the different levels of situation-awareness. The question is "how to operate a dynamic delegation to the machine in the case of autonomous vehicles?" Two points are of great importance: first, to propose interaction mechanisms for a delegation in confidence, according to typologies of use cases and scenarios that will present in the following and second, to select the most critical information in real time and determine how to communicate it and interact with it.

State of the art

In vehicles with autonomous capacities, the role of the Artificial Intelligence (AI) part is to provide mechanisms capable to fuse the information, select important contextual cues, and recommends appropriate actions to the user according to the context [15]. In order to improve the user experience while interacting with an autonomous or semi-autonomous vehicle, it is necessary to facilitate user's acceptance to different levels of autonomous vehicle's mechanisms. Recent works have proposed the use of contextual cues to provide more efficient and trustworthiness interaction between user and vehicles. Amor et al. [3] proposed a context-aware agent-based system to assist drivers to determine where and when to refill fuel to their car while the vehicle is part of a vehicle's ad-hoc network. Al-Sultan et al. [2] designed a real-time detection of driver's behaviour using onboard sensors. This context-aware system is able to detect and classify the driver's behaviour into four categories as either normal, drunk, reckless, or fatigued; and this information can be shared with other vehicles for safety. The dynamic behavior model can capture the static and the temporal aspects related to the behavior of the driver. Mobus et al. [27] designed a probabilistic machine-learning-based approach for the real-time prediction of the focus of attention and deficits of Situation Awareness (SA) using a Bayesian driver model as a driving monitor. This Bayesian driving monitor generates conditional expectations on the actions of the driver which are treated as evidence in the Bayesian driver model. Context-aware data used for this system are human behaviour manoeuvres (e.g., overtaking, turning), acceleration and distance between vehicles.

In human-vehicle interactions, there is a need of analysing and handling uncertainty to adjust to rapidly changing conditions. In these cases, the uncertainty of such sensor data can change rapidly over time and situations can sometimes be unpredictable [22]. In order to reduce these unexpected situations, Sanders et al. [31] proposed a shared control between the driver and vehicle sensors. In this approach, a trust-factor is calculated in real time for the vehicle driver and sensors help the human driver to drive their vehicle. Carlson et al. [8] presented a method to forecast direction and to adjust controller signals in order to cause the vehicle to travel in particular directions. Explainable models will also have to handle the loss of Situation Awareness (SA) that occurs when people oversee automation, limiting their ability to take back the control of the system and ultimately creating new types of failures [13]. In order to deal with high levels of uncertainty and unexpected situations, future XAI systems integrated to vehicles will need to be robust, adaptable to changing environment conditions or changing user behaviours, and be able to handle ambiguous and incomplete data [5].

Context & Scenario

Among the six levels of vehicle autonomy (from no automation to full automation) defined by the *National Highway*

Traffic Safety Administration (NHTSA) [1] , we deal with the level 3: conditional automation. We remind that a level 3 vehicle can perform most driving tasks as it has both environmental detection and decisions capabilities. However the driver must be in the vehicle and must remain alert and ready to take control if necessary. In order to be clearer in the rest of this article, we define the following terms: 1) the Passenger-Supervisor (PS) is the "human" in the car that may be a passenger when the vehicle is in the autonomous mode or a driver (supervisor) when the vehicle can not manage a situation (see illustrations figures 1 and 2; 2) the Autonomous Vehicle (AV) is seen as Command System (CS) commanding the vehicle (V).

Before tackling the issues, let us describe a driving scenario of an autonomy level 3. The AV drives, i.e. the CS controls the driving of the vehicle. Meanwhile the PS goes about its business(occupation) : he may read, look his emails, play, while being for example on a smartphone or a touch pad. This situation is going on until the AV detects a future problem in the driving control, a case that the CS cannot manage itself (e.g. defective sensor(s), very bad weather, etc.). At this moment the CS must give the control to the PS and the PS must be able to take back the control of the vehicle in a limited time. Thus the PS has taken the control (so drives) of the vehicle and the AV may be seen as "inactive". But once the problem is over, the PS may decide to stop driving and to give back the control of the vehicle to the CS of the AV. This transition has to be smoothly enough in order to keep the PS confidence in the AV and also for security reasons.

Figure 2: Guetty Images Illustration of PS (Passenger-Supervisor)

Through this short and simple scenario, several issues are raised, that in our knowledge, are not all solved. From this scenario, we may extract 4 phases of driving defined in figure 3. Phase 1 does not require more explanations as this is the current main situation of driving. Phase 2 has been widely studied, so several solutions have been experimented in a real-life context. However from an ergonomic point of view, acceptability and attention of human are two important focus points. To accept to be in an AV, a passenger has to be confident and feel secured. Maintaining attention is necessary as the AV may give back the driving within a short time. The interest points here are the two last phases: phases 3 and 4. Some questions need to be tackled: in phase 3, at which moment can the Command System CS stop its vehicle control? In other words when does the CS know or deduce that the PS is in a position to take the control of the vehicle and that the AV does not need to be stopped for security reasons? Considering the phase 4, similar issues are raised : when will the PS accept to let go of the steering wheel? when will he/she have confidence in the CS? We address the issues of phases 3 and 4 according to a pluridisciplinary point of view that combine computer science (AI and HSI), humanities and social sciences (ergonomics).

Analysing the retrieving control of the vehicle

At levels 3-4, the driver will be required to take back control of the vehicle when he/she wishes or when the system requires it, due to external (on the road, weather-related) or internal (sensor failures) failures. The activity of the PS will therefore alternate periods of manual driving and periods of Non Driving-related Activities (NDRA) [9]. While an "elimination" of the accident risk associated with the human factors is likely to occur during autonomous driving periods, new safety risks related to critical transition periods for controlling driving activity are to be expected. All these steps define a transition from autonomous driving to manual driving, and vice versa, which must occur in less than 10 seconds. More critically for the level 3, the manoeuvre of manual control resumption by the PS could occur in

Phase 1
Non-autonomous steering: the PS drives the vehicle (i.e. the CS of the AV is not active).

Phase 2
Autonomous control: the AV drives and the PS is a passenger.

Phase 3
Transition from Autonomous to Non-autonomous Piloting: the CS of the AV gives the vehicle control to the PS.

Phase 4
Transition from Non-autonomous to Autonomous Piloting : PS gives the vehicle control to the CS of the AV.

Figure 3: The phases of driving

emergency, due to failure or inoperability of the autonomous system [26, 28, 24]. In a ethnocentric approach of human machine interaction, three factors have to be taken into account in order to limit the deleterious consequences of a misfit transition modalities between the Autonomous system of the Vehicule AV and the Human information Processing System. These factors are attentional switch, situation awareness and expertise. From this perspective, designing an adapted HSI means ensuring good communication from the human to the system and vice versa.

Autonomous driving and attentional switch
From the Level 4, PS will then be able to switch from a sort of Non-Driving Related Activity (NDRA) to another one while the autonomous system will supervise driving for several hours, and then s/he will have to take back control of his vehicle despite his total commitment to this side activity. The period of alternation between two tasks has been the subject of much work in selective attention, underlining its critical nature for humans. Laberge [21] was the first to demonstrate a deterioration in both the quality of the response and the response time of participants in a protocol requiring them to switch between two distinct tasks: the switch. It would be the consequence of attention overload caused on the one hand by the inhibition of the processing of the current task, and on the other hand by the activation of the processing of the alternating task. The vehicle of tomorrow has then offer to the PS the possibility of safely regaining control of the driving activity, regardless of the secondary activity (external to driving; e.g., film viewing) in which he will engage when the autonomous system supervises the driving activity. The first issue to solve is centered on the transition phase. The question asked here is how the AV will communicate with the PS: by which perceptual modality the "off/on" next status should be presented to ensure that the PS first detects, then identifies and finally correctly reacts to the need of transition.

Autonomous driving and situation awareness
As already said, the autonomous driving phase could last several hours allowing PS to concentrate on a NRDA requiring strong workload. An intrinsic driver factor could also reinforce the already critical cost of alternation: loss of situational awareness [12, 23]. Recent studies show that the level of situational awareness decreases significantly in autonomous driving situations, especially when the PS is cognitively and attentively involved in an ancillary activity. As situational awareness requires time to be reactivated after the driver resumes driving, the PS's careful handling of critical visual cues of the road environment will be altered, potentially resulting in an over-risk. The question to be solved here is twofold. On the one hand, how to detect and identify the lose of situation awareness of PS in the autonomous driving phase. This will undoubtedly be achieved by the ability to process physiological data from physiological sensors (oculometric, cardiac, electro-dermal) online. And, on the other hand, how to accompany the PS to regain situation consciousness when he lost it. This will involve the design of a smart Human System Interface (HSI, in following) informing the PS on elements related to the traffic for example, and interacting with him.

Autonomous driving and driving expertise
The switch cost associated with alternating is very sensitive to the nature of the processes implemented in the alternating tasks. Thus, the switch cost is all the more important as the processes involved require careful control, which is very costly in terms of workload. On the other hand, the switch cost associated decreases when the task requires less workload, and implements more automated processes. Like many human skills (reading, writing, lacing shoes, etc.), driving is a process that is first carefully controlled

and which, through a long and repeated training, becomes automatic. Today, the majority of drivers are considered as experts in driving activity (driving licence for more than 5 years, and 10,000 km driven per year at least). Nowadays, young drivers and older ones are over represented in the second category of un- and weakly- experimented drivers. Since the expertise of the driving activity is built through experience and repeated exposure to various driving situations, future autonomous vehicles will not *a priori* allow these drivers to maintain and/or increase their levels of road expertise. Thus, for the same number of kilometres travelled per year, the PS could never achieve sufficient driving experience to be considered an expert driver. Since the level of control that the subject exercises over alternating tasks or activities is a determinant of the cost of alternation, it seems essential to think an HSI of resumption aid for the most critical populations.

Research directions

Used of autonomous car simulators
As shown previously, one of the most critical issue to solve (after technological ones) is to ensure a safety HSI cooperation, which is finally the determinant of its acceptability for the human. One way to ensure the development of HSI responding to the needs and constrains of the human factors is to include the focused final user earlier in the design of the system. Announced for 2020 in 2016, it is noticeable that the autonomous car of level 3 and more is still a project. A mean to test *a priori* the safety in the HSI is the used of autonomous car simulators. They have the advantage 1) to offer the possibility to test every HSI solutions without any safety risk for the PS whatever their inner characteristics, 2) to put the PS in exactly the same critical contexts, ensuring to replicate the measures and 3), to be clearly less costly than road experiments with a "real" autonomous car.

Design and evaluation of interaction techniques
In such context, the amount of information the user may want to access is very large: it includes the real time information reflecting the current state of the car, road information such as speed limit or traffic jam ahead, navigation information related to a path predefined on a map but also information explaining to the driver the decision the car has just taken. Interacting with this large information environment to annotate, consult, filter, or even share information, necessarily needs the use of multiple commands. In traditional desktop contexts, reaching these commands would require large and deep menus and sub-menus, while observing this information would require large screens. In the context of the car, large screens are prohibited. In the literature, multi-display environments have been widely explored [4, 6, 32, 29]. More recently the concept of data physicalization [19, 7, 10] seeks to embed data into physical objects serving as referents to the information, and tangible interfaces allow shape-changing and flexible properties to touch screen devices providing eyes-free interaction in a cockpit [17]. Ultimately, on-body interaction has been explored to offer new supports for accessing multiple commands and data [30, 16]. All these alternatives are promising approaches to handle large information space and to access commands. There are however intrinsic constraints in the context of vehicle cockpit: small sizes of displays, luminosity, lack of horizontal surfaces, limited interaction space. These limitations must therefore be considered to revisit these approaches and compare their applicability and benefits.

Promote acceptability through argumentation techniques
In the context of automated driving, an important problem will be the notion of "acceptability" that is clearly related to the notion of explanation. Indeed, the PS's trust will depend on the answer to the question: "why does the AV

take this decision?". Different approaches exist in literature, very often using explainable models (see for instance [20, 18]). These models are generally efficient but not formal and so it is very difficult to prove that they always give a good result. In another side, a complete formal theory exists that can be useful for producing explanations: the Argumentation Theory (see [11, 14]). So we think that the crossover of these two approaches will be interesting for solving our acceptability problem: argumentation theory could formally justify the behaviour of explainable models and also produce more readable explanations.

Conclusion

The goal of this position paper is to provide the automated driving and AI community, a clear view about the issues and the research directions regarding the problem of dynamic delegation between the driver and the vehicle in the case of autonomous vehicles (level 3 and 4). In order to deal with unexpected situations before and during the dynamic delegation phase, the Command System of the vehicle must ensure the integrity of information, such as robustness of different sources of data, information about the driver and the vehicle state and finally, the context and situational awareness. Adaptive and non-intrusive Human-Computer Interaction techniques must be designed and evaluated in order to provide the driver with customized and rapid control transition to the vehicle. These interaction techniques must have shape-changing and flexible properties and must be reinforced by several natural and multi-modal interaction mechanisms (speech, gestures, gaze and haptics). These multi-modal devices will be also used to alert the driver in case of critical situation or emergencies.

In addition, decision and collaboration capabilities are key factors that must be considered and characterized under different use cases for increasing safety and acceptability of the driver. Most importantly, we have shown the notion of "acceptability" as a main issue to address in order to increase the driver's trust of the vehicle decisions. In this case, a proposed solution consists in designing and developing mechanisms based on Explainable Artificial Intelligence (XAI) models to inform clearly to the driver the automated decision of the vehicle related to the control transition to the driver. Together with advanced interaction technique, this will provide (1) explainable model and (2) explanation interface [25].

Finally, a future perspective is the exploration of cognitive models to understand the situational awareness, the reaction time, the emotional state and behavior of the driver in different use cases. These models will be also adapted to different characteristics and capabilities of the driver (mental or physical disabilities, age, genre, etc.) considering different situations and/or interaction scenarios.

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