Notification in Automation: Haptic Feedback for Supporting Safety in Automated Driving

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Abstract
The automotive industry is introducing automated features at an unprecedented rate, performing tests across diverse levels of vehicle automation, as well as innovate and accommodate for the inevitable change in driver's role. Until such a time when vehicle automation is perfect, it will be necessary to communicate to vehicle users, the automated functions of the vehicle. This will ensure that users are updated on the vehicle's operations, remain situationally aware of the driving scenario, and to intervene in case of automation failure. Here, we discuss the available sensory channels of the user that could support such communications. In particular, we select the haptic modality for detailed discussion and discuss the opportunities it offers.

Author Keywords
Haptic Feedback; Autonomous Driving; Situational Awareness; Transfer of Control

CSS Concepts
• **Human-centered computing~Human computer interaction (HCI)**; *Haptic devices*; User studies;

A user challenge of vehicle automation
Recent years have witnessed strident trends towards autonomous driving. In spite of the enthusiasm

surrounding automated vehicles, the safety of vehicle users continues to be the primary concern of all relevant stakeholders. Ultimately, vehicle automation must be as effective as (or better than) a human driver. This is a non-trivial challenge when we consider the innumerable unforeseen events that we might never be able to develop algorithms for. Thus, it stands to reason that fully autonomous vehicles will not appear overnight. Currently, traffic consists of a mixture of vehicle automation. New vehicles with lane-keeping and adaptive cruise control share the same lanes as those with manual gear transmission. It has been estimated that the coexistence of (semi-)automated and traditional vehicles could last up to 30-40 years [10]. This means that inexplicable driving maneuvers of human drivers can continue to occur. Thus, users will have to retain some level of situational awareness of the driving scenario, even with automated vehicles, in order to intervene when vehicle automation fails to anticipate and respond appropriately to rare and unpredictable situations.

The need for situational awareness

Situational Awareness (SA) can be defined as a set of cognitive processes aimed at the perception of the elements of a situation (i.e. Level 1 of SA), understanding of their meaning (i.e. Level 2 of SA) and the anticipation of their evolution in the near future (i.e. Level 3 of SA) [4]. A recent review concluded that high levels of vehicle automation corresponded with lower user SA of the surrounding situation [3]. This resulted in larger delays in recovering control of the autonomous vehicle. Low situational awareness raises several challenges to the safe use of automated vehicles. First, users may remain ignorant to instances when vehicle automation respond inappropriately. For example, if an automated vehicle fails to detect a potential collision, it will not issue a salient warning. Such instances, even if they are rare, can be expected to happen as long as automation is not perfect. Second, as control of the vehicle passes from the machine to the human user, limited SA can slow down the decision-making process [5]. When the control changes hands, the driver must reach a certain degree of SA before performing a safe maneuver. The lower the SA when the machine is in control, the longer it will take to reach an appropriate level of SA, and consequently, the greater the risks to the safety of the driver, passengers and other road users. Third, low levels of SA may also result in the driver's poor ability to understand and explain why the autonomous vehicle has performed a particular maneuver. This lack of predictability and system comprehension leads to mistrust and results more generally in poor UX and acceptance [1]. To overcome these issues, it will be necessary to notify users during automated driving to allow them not only to intervene in a timely manner but also to be aware of the decisions taken by the vehicle.

Designing for safety and its limitations in autonomous systems

Periodic notifications could update vehicle users of the driving scene and vehicle automation. This could maintain the SA of vehicle users without compromising their experience of non-driving related activities. Traditionally, automotive user interfaces have focused primarily on the use of visual and auditory notifications. With visual notifications, information can be more unambiguously expressed. However, they often require focused visual attention (i.e., overt fixations). Auditory notifications, on the other hand, are omnidirectionally accessible. However, they tend to be transient.
It is worth noting that many consumer products are not typically designed to minimize conflicts between the limited resources of the user to process information [18, 8]. Visual notifications could remain unnoticed when the user is involved in activities that demand visual attention, e.g. driving [8]. Secondly, referring to manual driving, the driver directs 30% to 50% of his visual attention to secondary tasks [9] and that percentage can be expected to increase in automated vehicles where non-driving related tasks will be more

and more engaging and entertaining. Auditory stimuli also play an important role in distracting drivers. Drivers may often find themselves busy in chatting with other passengers or sometimes using the smartphone due to their verbal content or startling effect, increasing the allocation of his attentive resources and threatening their safety [6,11,17]. In addition, even drivers who are busy in handsfree smartphone conversations have a consumption of attentive resources that leads them not to notice critical points of traffic flow (i.e. traffic lights and signals), to react more slowly to the elements of the road that they noticed [15] and even to slower braking [16]. These arguments suggest that channeling information by auditory or visual cues may not be sufficient, as these two channels often have an already substantial attentional load.

Can haptics be the way forward?

Instead of visual or auditory notifications, haptic notifications could be used to convey information to an occupied vehicle user. To date, this channel is rarely engaged, as opposed to visual and auditory channels. As safety-critical warnings, haptic notifications tend to be rapidly perceived by drivers, particularly in warning drivers of rear-end collisions [14]. Ng & Alan (2012) [2] compared reaction times when users were presented with different response modalities (visual, auditory, and tactile). Response times were the shortest when responding to tactile stimuli, then followed by the auditory stimuli and then the visual ones. Interestingly, haptic perception appears to be resilient to the high cognitive load conditions of busy traffic conditions [12]. In a robotic surgery context [13], these three modalities were directly compared to assist the doctor in avoiding certain areas. Haptic notifications (i.e., warning) caused users retract surgical instruments from critical areas faster than visual or auditory feedback. These results are promising for the application of haptic notifications for supporting vehicleuser
communications as they to be more perceptible for drivers than visual and auditory feedbacks, and this advantage remains even under different cognitive load situations. Haptics can also go beyond physical contact with the driver. Ultrasonic interfaces can record in-air gestures and provide a perceptible response when the command is accepted. In fact, the system supplies for a sort of force field that allows user to perceive completely virtual keys and knobs in mid-air, projecting the sensations onto the fingers. This possibility can revolutionize how we conceptualize displays that can change "shape" as needed. The infotainment system can therefore be designed so that the driver never takes his or her eyes off the task at hand, be it a driving task or a secondary task. This would allow him/her to operate with the navigator or air conditioning safely without having to stare at the display every time. However, in order to draw definitive conclusions to implement haptic feedback in cars available on the market, it is urgent to develop experimental protocols to investigate real driving context. In doing so, the effectiveness of haptic feedbacks can also be studied and evaluated in situations of real stress and when people place too much trust in haptic warning and assistance.
There is a growing field of research in developing alert systems that include multi-sensory integration and augmentation, so a combination of sensory feedbacks should be considered for future implementation.

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