Transportation Research Part F 58 (2018) 678–692

Contents lists available at ScienceDirect

Transportation Research Part F

journal homepage: www.elsevier.com/locate/trf

The effect of peripheral visual feedforward system in enhancing situation awareness and mitigating motion sickness in fully automated driving

Juffrizal Karjanto [a,b,*], Nidzamuddin Md. Yusof [a,b], Chao Wang [b], Jacques Terken [b], Frank Delbressine [b], Matthias Rauterberg [b]

[a] Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia
[b] Department of Industrial Design, Eindhoven University of Technology, Eindhoven, The Netherlands

ARTICLE INFO

Article history:
Received 6 February 2018
Received in revised form 17 May 2018
Accepted 30 June 2018

Keywords:
Motion sickness
Situation awareness
Peripheral visual feedforward system
Mental workload
User experience
Fully automated vehicle

ABSTRACT

This study investigates the impact of peripheral visual information in alleviating motion sickness when engaging in non-driving tasks in fully automated driving. A peripheral visual feedforward system (PVFS) was designed providing information about the upcoming actions of the automated car in the periphery of the occupant's attention. It was hypothesized that after getting the information from the PVFS, the users' situation awareness is improved while motion sickness is prevented from developing. The PVFS was also assumed not to increase mental workload nor interrupt the performance of the non-driving tasks. The study was accomplished on an actual road using a Wizard of Oz technique deploying an instrumented car that behaved like a real fully automated car. The test rides using the current setup and methodology indicated high consistency in simulating the automated driving. Results showed that with PVFS, situation awareness was enhanced and motion sickness was lessened while mental workload was unchanged. Participants also indicated high hedonistic user experience with the PVFS. While providing peripheral information showed positive results, further study such as delivering richer information and active head movement are possibly needed.

1. Introduction

In fully automated driving, human drivers will no longer drive at the operational level but rather only within the strategic level according to Michon's definition level of driving (Michon, 1985). Michon distinguished three levels of driving: operational, tactical, and strategic. The operational level involves control tasks like braking and accelerating. The tactical level requires planning and controlled actions like overtaking another car. The highest level is the strategic level concerning for example, the route to be taken and the estimated time of arrival. Having a fully automated vehicle (AV), a human driver only decides on the final destination, and the vehicle will handle all the driving tasks and decisions. Therefore, human drivers become occupants and have the freedom to conduct their own preferred activities. Based on a study done by Schoettle and Sivak (2014) on users from China, India, Japan, US, UK, and Australia on what kind of activity one would like to do inside an AV, they found that roughly 50–60% of the respondents imagined themselves doing non-driving tasks (NDT) such as

* Corresponding author at: Fakulti Kejuruteraan Mekanikal, Universiti Teknikal Malaysia Melaka, Melaka, Malaysia.
E-mail address: juffrizal@utem.edu.my (J. Karjanto).

https://doi.org/10.1016/j.trf.2018.06.046
1369-8478/© 2018 The Authors. Published by Elsevier Ltd.

watching a television/movie, socializing with other passengers, working, reading, and sleeping to fill in their journey time. A similar finding was also reported by Kyriakidis, Happee, and De Winter (2015). Building complete situation awareness (SA) requires awareness about the surrounding as mentioned by Endsley (1995). She explained that there are three levels of SA in a dynamic situation: perception, comprehension, and projection. Engaging in the aforementioned NDT will make the AV passengers/occupants become unaware of their current situation and have less control regarding the intention of the AV (Diels & Bos, 2016; Diels, 2014). They will have lower SA and to make matters worse, most if not all of the attention will be channeled on the NDT making the AV occupants unprepared for the induced forces generated from the horizontal accelerations.

In-vehicle video watching has been shown to induce motion sickness (MS) to the passengers in both a survey study (Schoettle & Sivak, 2009) and an experiment (Isu, Hasegawa, Takeuchi, & Morimoto, 2014). Although video watching produces less MS when compared to reading inside the car (Kato & Kitazaki, 2008), mild symptoms of MS such as feeling queasy and dizziness may tarnish the whole automated driving experience. Humans are known to be prone to MS when exposed to low-frequency horizontal (longitudinal and lateral) accelerations especially within the 0.1–0.5 Hz range (Turner & Griffin, 1999). This could quickly develop in the urban areas where abrupt changes in longitudinal and lateral accelerations are likely to occur because of the geometrical landscape of the road such as roundabouts, junctions, and small-radius corners. An AV undertaking a corner or junction would produce sudden movement to its passengers who might not be aware of the current action of the vehicle. As a result, the incongruity of inputs coming from the passengers' visual, vestibular and somatosensory system would cause sensory conflicts to develop. The sensory conflict theory was first introduced by Reason and Brand in 1975, and it is the most accepted and utilized theory in explaining MS. A mismatch occurs when the sensations and perceptions from the current experience are different from the stored memory which a person has developed in his/her brain over time (Tal, Wiener, & Shupak, 2014). It usually occurs when a person is experiencing real motions (such as riding in a car, plane, or boat) or virtual motions (such as riding a motion simulator or watching a 3D movie). That is the reason why a human driver is less likely to get MS compared to passengers (Rolnick & Lubow, 1991), as the driver has control over the motion produced by the movement of the vehicle.

One way to avoid sensory mismatch is to make the required information available to the passengers of an AV. Such required information is, for example, the immediate intention of the AV that involves variation in the longitudinal and lateral forces. This information can be presented shortly before an important situation is about to occur (such as when a junction is approaching). One modality that can be used to deliver this information inside a moving AV is the visual modality, more specifically a light that is placed within the peripheral view of the user.

Löcken et al. (2017) summarized the insights and guidelines regarding peripheral displays or adaptive ambient displays as they specifically termed them. For the current application in automotive, they suggested the use of peripheral displays to lower the mental workload, improve awareness, and also to display the vehicle's state. Peripheral and ambient lights information systems have been previously utilized in simulator and on-road studies. Most of the past work focuses on assisting the human driver in partial automation, for example, as a navigation aid (Matviienko, Löcken, El Ali, Heuten, & Boll, 2016), future traffic situation assistance (Laquai, Chowanetz, & Rigoll, 2011), lane changing decision support (Löcken Heuten, & Boll, 2015; Löcken, Müller, Heuten, & Boll, 2015), feedback about perception of speed (Meschtscherjakov, Döttlinger, Rödel, & Tscheligi, 2015), and communication between passenger and driver (Trösterer, Wuchse, Döttlinger, Meschtscherjakov, & Tscheligi, 2015). Within the fully automated driving context, in one study, a proximal light display was implemented as a wearable device to increase the SA when the users were not paying attention to the road and focusing on reading as the NDT (van Veen, Karjanto, & Terken, 2017). They found that although the SA was improved without the need to observe the environment outside the vehicle, the proximal light display distracted the users from their NDT.

The primary objective of this study was to investigate if the peripheral information helps to protect the AV occupants from getting MS. A peripheral visual feedforward system (PVFS) was designed to provide the information about the upcoming navigational actions of the AV. The navigational information was abstracted into light movement and presented in the periphery of the attention. It was hypothesized that the gained information from the PFVS increases SA regarding the future navigational direction of the AV and also reduces the level of MS experienced by the AV's occupant. In addition, it was hypothesized that the given peripheral light information does not increase the mental workload nor degrade the experience of the primary task of the AV's occupant, in our case watching a video. The study was performed on an instrumented car that behaves like a real AV on the real road. Since this was not a driving simulator study, analyses of consistency of the test rides will be discussed. Afterward, SA, MS, and mental workload were quantitatively analyzed. User experience in interacting with the PVFS was also assessed.

2. Methodology

2.1. Experiment design

A within-subject design was implemented, as suggested by Isu et al. (2014) in dealing with dropouts in an MS-related experiment. The independent variable was the study condition while the dependent variables were MS, SA, and mental workload. In this study, all the participants had to go through two conditions. One condition was without the PVFS and was termed control-condition, and the other condition was with the PVFS and was termed test-condition. The order of conditions was counterbalanced to control carry-over effects. Conditions were executed at least three days apart to make sure that if MS occurred within the first condition, it would not affect the result in the second condition. All the test rides were