The Car That Cares: Introducing an in-vehicle ambient light display to reduce cognitive load

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ABSTRACT

Driving is a cognitively demanding task. Hence, it is necessary to keep the driver's cognitive load in mind while designing new assistant systems. In this paper, we will present first goals of the recently started project "The Car That Cares". One goal is to keep the driver's workload low by adapting the information display to the driver's abilities and available cognitive resources. We want to find out if peripheral vision is a less demanded resource while driving and therefore propose ambient light as an alternative modality for information presentation. Furthermore, we present our approach to measure the driver's cognitive load using *functional Near-Infrared Spectroscopy (fNIRS)* and other techniques.

Categories and Subject Descriptors

H.5.m [**INFORMATION INTERFACES AND PRESENTATION (e.g., HCI)**]: MISCELLANEOUS

General Terms

Design; Human Factors; Measurement.

Keywords

peripheral interaction; ambient light; cognitive load; brain imaging; fNIRS.

1. INTRODUCTION

One of the research objectives of our recently started project *The Car That Cares (CtC)* is to find how in-vehicle assistant systems can adapt to the driver's state (e.g. health or cognitive state). In the process, we are looking into alternatives to existing assistant systems and interactions between driver and vehicle as well as into how to measure the driver's state.

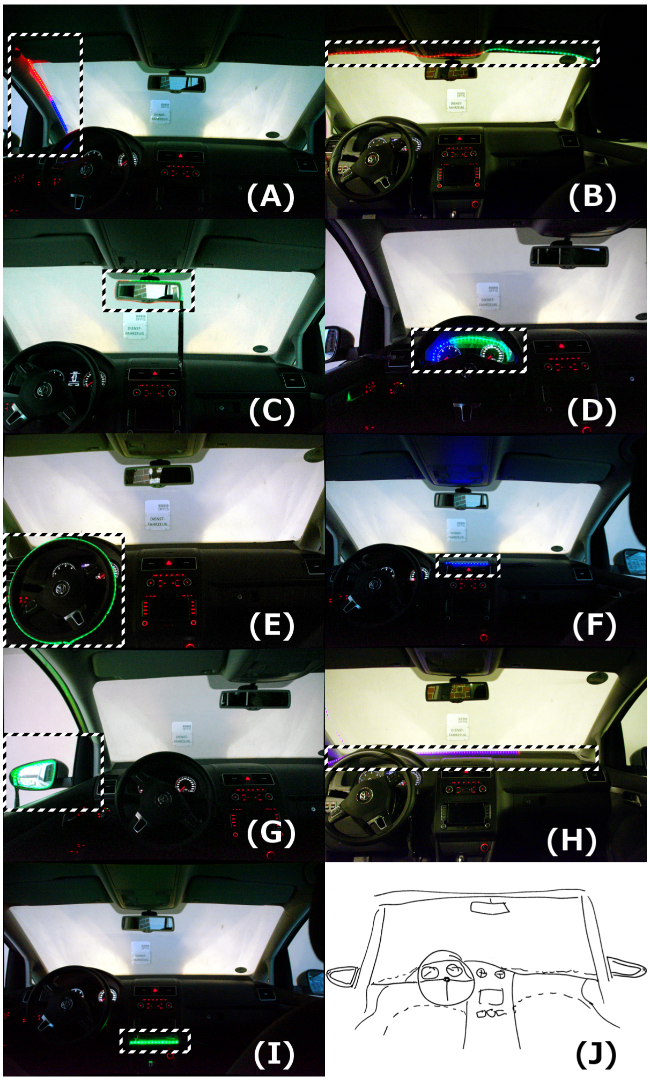

Figure 1: (A-I) show different locations for the ambient light display. (J) shows the image where participants could sketch their ideas.

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Coughlin et al. tried to increase safety by alerting or calming the driver depending on his or her arousal [2]. They studied methods to assess the driver's state, such as measuring skin conductance or eye movement. In addition, they motivated concepts for displaying information, including a light display. We want to manage the driver's cognitive load by adapting the interface to environmental conditions as well as the abilities and current cognitive load of a driver. We argue that the load is reduced if information is presented via a less demanded resource, following Wickens' multiple resources theory [22].

Many modalities addressing different cognitive resources have been introduced to the automotive domain. For example, navigation devices using vibro-tactile, visual or auditory cues (e.g. [8, 9, 10]). In addition, warning systems using visual icons, haptic feedback or auditory signals alone or in combination were tested (e.g. [1, 7]). As discussed in [22], peripheral vision and foveal vision demand different mental resources. This makes peripheral vision an interesting alternative. Our previous work (e.g. [14]) has shown that ambient light can be utilized to present information in other domains. Laquai et al. introduced an in-vehicle light display to keep safe speed [11].

In the following, we will discuss how we plan to find a suitable position of an in-vehicle ambient light display. Furthermore, we will introduce designs for our evaluations. In addition, we will present how we plan to measure the cognitive state of a driver using different techniques. Thereby, we will focus on *functional Near-Infrared Spectroscopy (fNIRS)*.

2. POSITIONING THE LIGHT DISPLAY

Tönnis et al. gave guidelines on where to place displays in cars amongst others [20]. However, their guidelines for visual displays focus on displays that need focused attention. Complementing this, we want to explore the possible locations of an ambient light display, which is seen peripherally.

Following a user-centred process, we performed a brainstorming session with five drivers and identified several locations for light displays. In a recently conducted online-survey, we presented nine of these locations to participants and asked them to rate the locations. Figure 1 shows these locations. At the end of the survey, participants could propose own ideas of an ideal position. Furthermore, they were able to give additional feedback.

Taking this approach enables us to reach more participants and thereby using fewer resources compared to inviting drivers to a lab study and presenting different implementations of real prototypes. However, this approach must not replace follow-up studies using hardware prototypes, where effects of different locations on the driver's perception are measured.

First results show that most participants preferred the dashboard as location for the light display as shown in Figure 2. Participants also rated the dashboard to be the most perceptible location. A detailed discussion of this survey will follow in another work, as the results are yet to be analysed. After the analysis, we will be able to limit the number of needed prototypes for the evaluation in more realistic conditions.

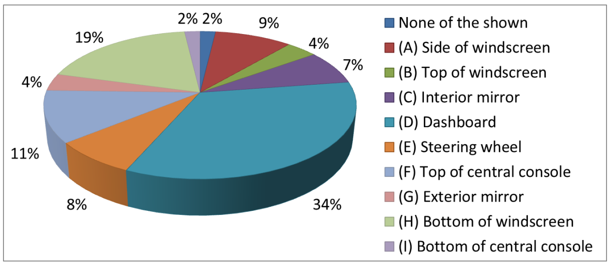

Figure 2: Out of 58 participants, 5 did not choose a favourite location for a light display. 34% of the remainder chose *At the dashboard*, while 2% chose the option *None of the shown*. *At the bottom of the central console* is the least preferred location (2%).

3. DESIGN OF THE EVALUATIONS

In the future, our display should assist the driver in all safety relevant driving situations. However, we decided to investigate one scenario as a starting point. The lane-change test as for example described in [18] is well documented and therefore publicly replicable. For our evaluations, we adapt this test by adding other road users and measure how drivers responded using different lane-change support systems, such as the light display. In this way, we are able to additionally measure the driver's decisions depending on the situation.

An example for a situation within our proposed scenario "lane change and overtaking manoeuvre" is illustrated in Figure 3: If the red car wants to overtake the bus, it needs to change the lane. The situation may be dangerous, if the driver is not aware of the blue car behind. To alleviate the problem, our display will shift the attention of the driver to if the blue car has not been seen. A possible behaviour for a light display in that situation may be a red flashing point of light that moves from the centre of view towards the left sight of the driver to shift his or her attention. However, this is just an example and may not be suitable at all, as finding possible behaviours is one aim of our future research. Further, we need to assess the driving situation and the driver's state before selecting an appropriate modality like ambient light, to display information to the driver if needed.

For our first evaluation, we plan to create a few prototypes of light displays at different locations in a driving simulator. The primary task of a driver is to overtake other cars. Concurrently, a driver needs to judge if it is possible to overtake based on his assessment of the current situation. We will measure the cognitive load of a driver performing these tasks in a baseline condition (no assistance) and different

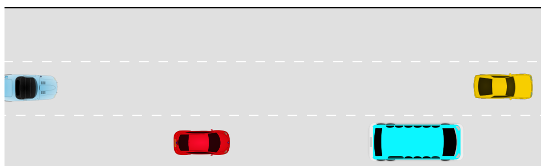

Figure 3: Example situation: The driver of the red car wants to overtake the bus, but needs to consider the blue and yellow car.

prototypes of the ambient light display. In doing so, we plan to answer the following questions: Can *fNIRS* be used to assess cognitive load? Does the location of a light display, regardless of its behaviour, significantly affect the cognitive load? In the future, we plan to use the same approach to evaluate different behaviours and other modalities.

4. COGNITIVE LOAD MEASUREMENT

In this section, we propose our approach on different techniques to measure a driver's cognitive load. We will further describe how we plan to find out if *fNIRS* can be used to monitor the driver's state (including load) in real-time.

4.1 Self-assessment

In previous works, we successfully used the *NASA Task Load Index (NASA-TLX)* as a self-assessment technique. The NASA-TLX is one of many post-hoc techniques that use questionnaires and are described in [5]. The main benefits of questionnaires are that it is easy to collect and analyse the data. However, it is not possible to gather the data during the tasks which may distort the results. In addition, self-assessment techniques collect the subjective impressions of drivers which may differ from their actual cognitive load. Despite that, NASA-TLX is often used in other studies. Hence, using it as additional measure will enable us to compare our results to related work more easily. Still, we need a real-time measurement and more accuracy.

4.2 Measuring the driver's performance

Another way to evaluate cognitive load is to measure the performance of a driver (e.g. braking response times) when solving secondary tasks that demand cognitive resources (e.g. setting up a navigation device). This way it is possible to measure the impact on cognitive load for different tasks, assuming that driving performance is related to the cognitive load. A tertiary task (e.g. n-back) can be added to increase the load and compare the impact on it for different secondary tasks at a higher level of cognitive workload. However, using this technique will only provide insights to the performance of a user at different levels of load and not on the cognitive load itself. Furthermore, it is highly dependent on the design of the tasks. On the other hand, this technique can be used to find correlations between cognitive load and physiological parameters as it was for example done by Reimer et al. in [19]. In our scenario, the driver's secondary task is to judge if it is possible to overtake based on his assessment of the current situation with the help of our light display, compared to judging without assistance.

As described, self-assessment and performance-based measurements can be used during evaluation. Nevertheless, our multimodal display should eventually be able to adapt to the driver's state, including cognitive load, in real-time. Measuring physiological characteristics, such as pupillometry (e.g. [17]), heart rate or skin conductance (e.g. [19]) can be used to assess the cognitive workload in real-time, but is still restricted in its validity, as changes in those parameters are only indicators for cognitive load. The origin of cognitive load occurs in the brain. Hence, using brain imaging to study cognitive load is a direct measurement criteria. There have been studies where brain imaging has been used to assess cognitive load [6, 13] and we decided to stick with this approach. Later, we may integrate other physiological parameters to increase the accuracy and robustness of the assessment.

Figure 4: Measurement Cap used with the *fNIRS* system. Source: [16].

4.3 Measuring cognitive load using fNIRS

In the project CtC, we use the *functional Near-Infrared Spectroscopy (fNIRS)* system to study brain activity. The *fNIRS* system measures the absorption changes on sub-surface tissues of the brain. Low-energy optical radiation is transmitted using light sources and the local concentration changes of oxy-hemoglobin and deoxy-hemoglobin is measured using optical detectors which can be correlated as a function of brain activity [15]. Figure 4 shows a set-up of the source-detector pattern on the measurement cap used in *fNIRS* analysis. We use this technique to measure neurophysiologic activities in the left dorsolateral prefrontal cortex (DLPFC) and right ventrolateral prefrontal cortex (VLPFC) as these areas correspond to the cognitive areas of the brain [13].

fNIRS has some advantages over other techniques like functional magnetic resonance imaging (fMRI [21, 4]), electroencephalography (EEG) or magnetoencephalography (MEG). *fNIRS* measures both oxy- and deoxy- Hb concentrations and this extra dimension helps in motion artifact removal [3]. fMRI requires a strong magnet and produces loud noises. The subject is constrained to a supine position during scanning making it unsuitable to measure brain activity under normal working conditions. EEG cannot really differentiate between brain areas and takes much longer to set-up compared to *fNIRS* [12]. MEG provides better spatial resolution compared to EEG but it is highly sensitive to head movements just like fMRI.

As mentioned in section 2, we plan to implement prototypes of different light displays at different locations (peripheral visual feedback). We plan to measure the brain activity for different locations and to compare brain activation patterns to reference measurements obtained while subjects performed a low visual cognitive workload driving task to assess cognitive work using brain activation measures [6]. This data should make it possible to judge the workload induced by the location of the light in order to select the locations that induce least amount of cognitive workload. Based on this analysis, we will be able to compare different light patterns at a specific location using the same technique. We also intend to incorporate other multimodal displays like audio, audio-tactile or vibro-tactile cues in the future.

5. CONCLUSION

We presented our first goals in the project "The Car That Cares". Following Wickens' multiple resource theory ([22]), we argue that it is possible to reduce the cognitive load by displaying information to a less demanded cognitive resource. As a first step towards an adapting multimodal display, we investigate if ambient light is a modality that can be used to send information to a driver. Therefore, we asked drivers as to which location of an ambient light display would be suitable and plan to evaluate the influence on cognitive load for a subset of these locations.

We plan to use an adapted lane-change task in a driving simulator as scenario for our evaluations. In addition to the driver's performance, we will measure the cognitive load using NASA-TLX and *fNIRS*. NASA-TLX is thereby used to evaluate the validity of the assessed load using *fNIRS*. Later, other physiological measurements may be added to receive more reliable results or increase the driver's acceptance.

Another short-term goal is to find a location for the ambient light display and evaluate different patterns of lights. Later, we would like to look into other modalities and create a multimodal display. Eventually, this display should be able to adapt to the driver's state and divert his or her attention to unnoticed dangers if needed.

6. ACKNOWLEDGMENTS

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7. REFERENCES

[1] E. Adell, A. Varhelyi, M. Alonso, and J. Plaza. Developing human-machine interaction components for a driver assistance system for safe speed and safe distance. *Intelligent Transport Systems, IET*, 2008.

[2] J. Coughlin, B. Reimer, and B. Mehler. Monitoring, managing, and motivating driver safety and well-being. *IEEE Pervasive Computing*, 2011.

[3] X. Cui, S. Bray, and A. L. Reiss. Functional near infrared spectroscopy (nirs) signal improvement based on negative correlation between oxygenated and deoxygenated hemoglobin dynamics. *NeuroImage*, 2010.

[4] X. Cui, S. Bray, and A. L. Reiss. Speeded near infrared spectroscopy (nirs) response detection. *PLoS ONE*, 2010.

[5] V. J. Gawron. *Human performance, Workload, and Situational Awareness Measures Handbook.* CRC Press, 2008.

[6] L. M. Hirshfield, E. T. Solovey, A. Girouard, J. Kebinger, R. J. Jacob, A. Sassaroli, and S. Fantini. Brain measurement for usability testing and adaptive interfaces: an example of uncovering syntactic workload with functional near infrared spectroscopy. In *Proc. CHI '09*, 2009.

[7] C. Ho, N. Reed, and C. Spence. Multisensory in-car warning signals for collision avoidance. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 2007.

[8] D. Kern, P. Marshall, E. Hornecker, Y. Rogers, and A. Schmidt. Enhancing navigation information with tactile output embedded into the steering wheel. In *Pervasive Computing.* Springer Berlin Heidelberg, 2009.

[9] S. Kim and A. K. Dey. Simulated augmented reality windshield display as a cognitive mapping aid for elder driver navigation. In *Proc. CHI '09*, 2009.

[10] A. L. Kun, T. Paek, v. Medenica, N. Memarović, and O. Palinko. Glancing at personal navigation devices can affect driving: experimental results and design implications. In *Proc. AutomotiveUI '09*, 2009.

[11] F. Laquai, F. Chowanetz, and G. Rigoll. A large-scale led array to support anticipatory driving. In *IEEE Int. Conf. on SMC*, 2011.

[12] J. C. Lee and D. S. Tan. Using a low-cost electroencephalograph for task classification in hci research. In *Proc. UIST '06*, 2006.

[13] R. McKendrick, H. Ayaz, R. Olmstead, and R. Parasuraman. Enhancing dual-task performance with verbal and spatial working memory training: Continuous monitoring of cerebral hemodynamics with nirs. *NeuroImage*, 2013.

[14] H. Müller, A. Kazakova, M. Pielot, W. Heuten, and S. Boll. Ambient timer – unobtrusively reminding users of upcoming tasks with ambient light. In *Human-Computer Interaction – INTERACT 2013.* Springer Berlin Heidelberg, 2013.

[15] NIRx Medical Technologies LLC, 15 Cherry Lane, Glen Head, NY 11545, USA. *NIRStar 12.4, User Manual.*

[16] NIRx Medical Technologies LLC, 15 Cherry Lane, Glen Head, NY 11545, USA. *fNIRS Measurement Caps, User Manual*, 2012.

[17] O. Palinko, A. L. Kun, A. Shyrokov, and P. Heeman. Estimating cognitive load using remote eye tracking in a driving simulator. In *Proc. ETRA '10*, 2010.

[18] T. A. Ranney, G. Baldwin, S. M. Vasko, and E. N. Mazzae. Measuring distraction potential of operating in-vehicle devices. Technical report, NHTSA, 2009.

[19] B. Reimer, B. Mehler, J. F. Coughlin, K. M. Godfrey, and C. Tan. An on-road assessment of the impact of cognitive workload on physiological arousal in young adult drivers. In *Proc. AutomotiveUI '09*, 2009.

[20] M. Tönnis, V. Broy, and G. Klinker. A survey of challenges related to the design of 3d user interfaces for car drivers. In *Proc. 3DUI '06*, 2006.

[21] S. Waldert, L. Tüshaus, C. P. Kaller, A. Aertsen, and C. Mehring. fnirs exhibits weak tuning to hand movement direction. *PLoS ONE*, 2012.

[22] C. D. Wickens. Multiple resources and mental workload. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, 2008.