Towards User-Focused Automated Vehicles Supporting Mobile Office Work

Klas Ihme, Institute of Transportation Systems, German Aerospace Center (DLR), Germany, *klas.ihme@dlr.de*, **Fabian Walocha,** DLR, **Jan Wegener,** DLR, **Johannes Rehm,** DLR, **Gavin Grolms,** DLR, **H. Phuong Nguyen,** DLR, **Mathias Niedling,** Light Laboratory / HCC-LLAB, HELLA GmbH & Co. KGaA, Germany, **Denis Elster**, DLR, **Alexander Trende,** OFFIS - Institute for Information Technology, Germany, **Dario Niermann**, OFFIS - Institute for Information Technology, Germany, **Uwe Drewitz,** DLR

ABSTRACT

Advances in the development of vehicle automation promise that humans may soon be relieved from the burden of manual driving at least during certain phases. For instance, humans in future vehicles may use the cockpit as mobile office when highway automation is activated, but be the driver in rural areas, when full automation is not available. Since mobile office workers have different needs than drivers, this imposes specific requirements on in-vehicle software and hardware. One option to meet these requirements is the development of user-focused automation that puts human needs into the centre of system design. Systems with user-focused automation derive the current needs of the occupants by combining user and context monitoring using various sensors in real time. Based on this, the system behaviour could be adapted by adjusting the interior lighting or the information on a human-machine interface. Here, we present the current status of the development of a driving-simulator-based demonstrator for the interior of an automated vehicle supporting mobile office work through user-focused automation. In a first driving simulator study, we developed a real-time capable classifier to estimate the user's current activity (driving, relaxing or working) and stress level. Next, we evaluated how different concepts of interior lighting including spectrally-adaptable ambient lights and focused spot lights as well as changes in the navigation system can support the different activities. In a final study, the different components will be integrated and evaluated to demonstrate the potential of user-focused automation to support varying needs of users in automated vehicles.

Keywords: User-focused automation, interior lighting, user activity recognition, user monitoring, automated vehicles.

1 BACKGROUND

Increasing vehicle automation promises that human may soon (at least partly) be relieved from the burden of manual car control and then could devote their time and attention to activities such as relaxing, reading or even use their car as mobile office (Pollmann, Stefani, Bengsch, Peissner, & Vukelić, 2019). Probably a great share of future vehicles will not be fully automated in a sense that the user never has to drive, but will allow automated driving only in certain sections, so that users may have to resume control when automation boundaries are reached. This imposes new requirements on the design of in-vehicle software and hardware, because users want to or have to change between very different activities even within one ride. Notably, the needs of mobile office workers with high task load differ from users who work on routine tasks, relax or drive manually. Hence, if vehicles offer multiple automation levels and thus allow different usages of the vehicle interior, they will have to be able to adapt to the user needs in the current situation. Otherwise, user acceptance for concepts of automated driving that promise to gain time for other tasks cannot be ensured. A design approach for ensuring this is the concept of user-focused automation (Drewitz et al., 2020), which puts basic human needs in the centre of system design. As a prerequisite for meeting basic and current user needs, user-focused systems therefore require a reliable real-time estimation of the user’s current state as well as adequate strategies for supporting the users.

2 OBJECTIVES

Building on the aforementioned considerations, the main objective of this work is to build a demonstrator set-up for a user-focused automated vehicle interior that can determine the user’s current activity and stress level and based on this, supports the user when accomplishing mobile office work or relaxing. Here, we give a brief overview on the process for the development of the real-time user model (Study 1) and the evaluation of different intervention strategies (Study 2). Unfortunately, a final evaluation of the entire system (Study 3) with real-time adaptation had to be postponed due to restrictions designed to contain the spread of coronavirus and will be conducted in late 2021.

3 DEMONSTRATOR SET-UP

The demonstrator set-up was implemented in a driving simulator (see Figure 1). The used simulator mock-up has a standard LED band-based HMI for communicating mode awareness (Figure 1, orange). In addition, the mock-up was equipped with a display HMI (tablet-based, Microsoft Surface Tablet with 12.3 inches) that displays a navigation system (Figure 1, blue) to communicate route adjustments. The adaptable interior lighting concept included an ambient light as well as matrix LED reading light. The ambient light was implemented by means of a spectrally freely adjustable light panel using RGBW LEDs (red, green, blue, white LED) as a light source. The panel illuminated the vehicle interior as an indirect light source (Figure 1, red). The matrix LED reading light was integrated as a focus light, which can specifically illuminate the work area in the mobile office (Figure 1, green). The demonstrator was used as vehicle mock-up for the two driving simulator studies described in the following.

4 STUDY 1 – DEVELOPING A REAL-TIME CAPABLE USER MODEL

The overarching goal of Study 1 was to develop a real-time capable user model that can determine the current activity of the user and estimate his or her stress level as prerequisite for the final demonstrator. As data base for this, a driving simulator study with an earlier version of the demonstrator was conducted in which participants accomplished the relevant activities with varying stress levels. The study is described here in brevity and details can be found in Walocha, Drewitz, and Ihme (in review).

Figure 1. Demonstrator set-up in driving simulator. The interior elements are framed by coloured rectangles (orange: HMI for communication mode awareness, blue: display HMI for navigation system, red: ambient light, green: matrix LED reading light).

In total, 29 participants (mean age: 25 years, 14 females and 15 males) were included in the analysis. As basis for activity and stress recognition, participants' upper body was filmed with a webcam mounted on the right A-pillar and their heart rate (HR) and HR variability (HRV) was assessed using a 3-lead electrocardiogram. Each participant experienced four driving scenarios of roughly 15 minutes each: manual driving (MD), plus three automated drives relaxing (REL) and mobile office with high (MO-HT) as well as low task load (MO-LT). The data were then used to develop a user model that discriminates three activities (manual driving, relaxing and working) and two stress levels (high versus low). For this, we extracted information about the location of a set of body points in participants' upper bodies from each video frame using OpenPose (Cao, Hidalgo, Simon, Wei, & Sheikh, 2021) as input for pose and activity recognition (see Figure 2A). The user model first determines the current pose (driving = hand on wheel, head straight; relaxing = hands on lap, head variable; working = hands on keyboard or mouse, head towards screen) using a support vector classifier for each frame based on the pre-processed body points. The pose values are then integrated over time in a sense that the current activity is determined by the pose occurring most frequently in the last 30 s. In parallel, the current HR and the HRV of the last 30 s (sliding windows of 30 s with 1 s overlap) were used to estimate the current arousal (high = high HR, low HRV; low = low HR, high HRV) based on Gaussian mixture modelling for each second. Based on this, the current stress level is calculated by averaging the arousal level of the last 30 s (see Walocha et al., in review).

The classifier for the activity estimation showed very good performance for discriminating between working and the other two activities. Despite some difficulties discerning driving and relaxing in a sense that the relaxing poses were partly classified as driving, the classification accuracy is still acceptable for these activities (see Figure 2B). The stress estimator provided reasonable results with identifying the highest stress ratings during MO-HT, followed by MO-LT and MD. Lowest stress values were estimated for the REL condition (see Figure 2C). In sum, the results appear to be a good first step for the real-time user model of the demonstrator.

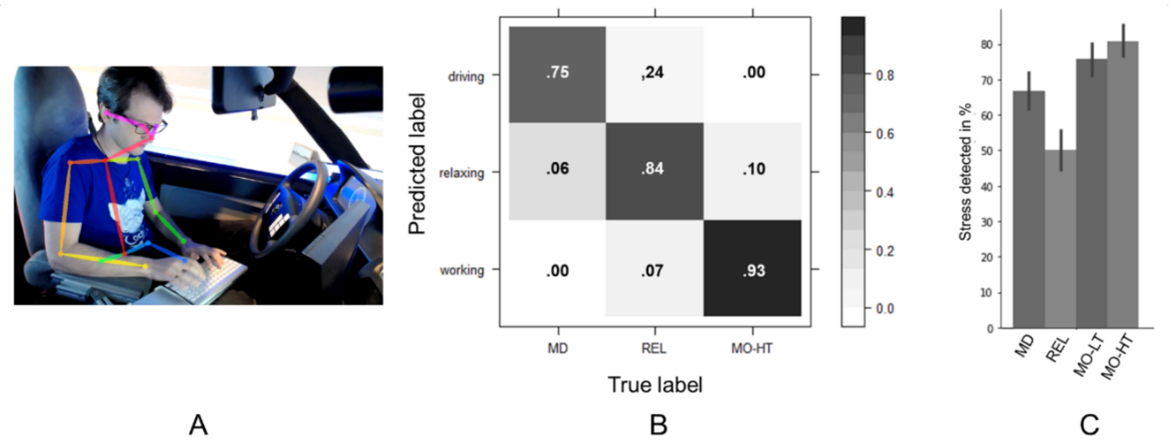

Figure 2. Study 1: (A) Interior setup recorded from camera on A-pillar with OpenPose body points overlaid. (B) Confusion matrix of activity classification. (C) Results of stress detection stratified by drives (mean and standard error of the mean).

5 STUDY 2 – EVALUATION OF INTERVENTION STRATEGIES

This main goal of Study 2 was to evaluate the usefulness of a set of intervention strategies that have been designed for this use case to support the users during mobile office work. For this, an interieur light concept that ought to support users accomplishing the different activities as well as an adaptation of the navigation system were integrated into the demonstrator set-up.

5.1 Methods

A total of 51 volunteers (16 females, 35 males, mean [M] =34.5 years, standard deviation [SD] = 12.6) participated in the study. After a short training, participants drove four experimental runs in fixed order (Learning Phase [LP], Repetition Phase, [RP], Pressure Phase [PP], and Relax Phase [RP]). For these, participants were told as a cover story before each run that a 15-minute drive to an appointment would follow. Eight minutes of the drive were automated and could be used to work on the on a mobile office task (which was an improved version of the task from Study 1), while the rest of the time had to be driven manually (in fact, however, a takeover never occurred and the scenarios stopped after the automated drive). In LP, participants had to perform the office task with a low task load (low difficulty in emails, 75 sec + up to 20% time between emails). During RP, participants had to perform the task with a medium task load (medium difficulty on the emails, 60 sec + up to 20% time between emails). For PP, the task had to be performed with a high task load (high difficulty of emails, 45 sec + up to 20% time between emails). Finally, in REL, participants could relax during the automated drive.

A between-groups design was used to evaluate different interventions to adapt the interior and the route to the stress level of the participants. For the mobile-office task, there was the following adaptations:

- Interior adaptation: one experimental group (18 participants) received an interior light adaptation shortly after the start of the mobile office task in RP and PP, respectively, consisting of switched-on focus light and a stimulating ambient light with high colour temperature and high brightness (about 6500 Kelvin, cool white LED). The control group received no adaptation (16 participants). The small number of participants in the two groups resulted from technical problems with the interior adaptation for 17 participants.

- Route adaptation: One experimental group (25 participants) received the option to adapt the route after about 6 minutes on the navigation system during the processing of the mobile office task in PP, so that a longer automated drive (and thus more working time) were available with a similar arrival time. Participants could confirm or reject the route adjustment. The control group (26 participants) was not given the option to adjust the route.

During REL, a further adjustment of the interior lighting was evaluated. Here, the ambient light was set to a reduced colour temperature (approximately 2800 K, similar to an incandescent bulb), which was experienced by the experimental group of 17 participants). The control group consisted of 15 participants. Again, the small number of participants resulted from technical problems with the interior adaptation in the remaining participants.

After LP, RP and PP, participants provided a self-report of their experienced stress (State Stress Questionnaire, SSSQ; Helton & Näswall, 2015) and rated the acceptance of the adaptations with the Acceptance Scale by van der Laan, Heino, and Waard (1997). In case of the route adjustment, we asked participants whether and why (not) they had accepted the route adjustment. After the REL, participants completed a self-developed relaxation questionnaire and the van der Laan scale. These ratings on the questionnaires after PP and REL were used to evaluate the adaptions during mobile office work and relaxing, respectively, by comparing the different experimental groups with non-parametric Mann-Whitney-Tests.

5.2 Results

For the mobile office condition (PP), no significant effects were revealed in the SSSQ and the acceptance scale (all ps > .05) between the groups with and without interior light adaption. In addition, no differences in the SSSQs were revealed for the route adaption (all ps > .05). However, participants provided higher ratings regarding usefulness (Z=-4.65, p < .001) and satisfying (Z=-3.88, p < .001) on the acceptance scale for the route adaption (Figure 3). For relaxing, there were no significant differences in the SSSQ, the van der Laan acceptance scale and subjective relaxation between the groups with and without light adaptation (all ps > .05).

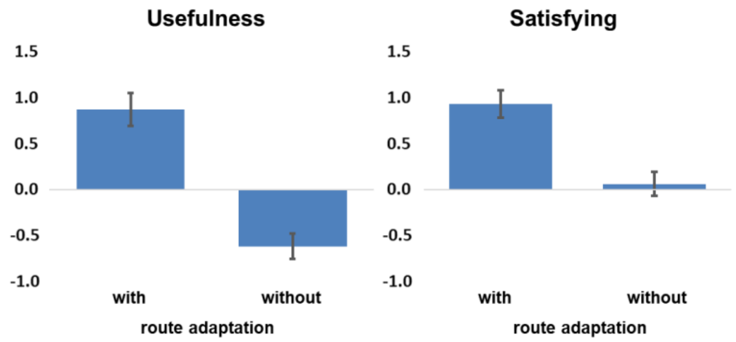

Figure 3. Study 2: Rating on the van der Laan acceptance scale for the route adaption in the mobile office condition (right: subscale usefulness, left: subscale satisfying).

5 IMPACT

In this work we presented building blocks to set-up a demonstrator of a user-focused automated vehicle interior that supports mobile office work. First of all, it could be shown that a real-time recognition of different relevant user activities and the stress level is feasible based on camera recordings of the upper body and ECG measurements. In addition, we implemented two potential intervention strategies based on interior lighting and routing that can adapt to the recognized user state and by that offer tailored support for a mobile office. The next step is now to optimize these intervention strategies and to evaluate the final demonstrator with all building blocks included, which is planned for autumn 2021. Although recent work has developed ideas for adaptive interiors for mobile office work (e.g. Pollmann et al., 2019), this demonstrator will be the first real-time system integrating user monitoring with an adaptable interior in a user-focused way.

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