Adaptive Dark Mode: Investigating Text and Transparency of Windshield Display Content for Automated Driving

Andreas Riegler
University of Applied Sciences Upper Austria
Hagenberg, Austria
andreas.riegler@fh-hagenberg.at

Andreas Riener
Technische Hochschule Ingolstadt
Ingolstadt, Germany
andreas.riener@thi.de

Clemens Holzmann
University of Applied Sciences Upper Austria
Hagenberg, Austria
clemens.holzmann@fh-hagenberg.at

Figure 1: Chat application on a windshield display with variants of background transparency: fully opaque, fully transparent, luminance-adaptive (left to right).

ABSTRACT

Windshield displays are a promising technology for automotive application. In combination with the emergence of highly automated vehicles, chances are that work-related activities will become more popular on the daily commute to and from work. While windshield displays can show content relevant for non-driving related activities, little information is available on how potential users would utilize these displays in terms of text and background color as well as transparency usage. In this paper, we present the results of two user studies (pilot study: $N = 10$, main study: $N = 20$) addressing this issue. Findings from quantitative measurements and qualitative pre-/post study surveys and interviews suggest a strong preference for the chat window being located on the driver side presented in dark mode with adaptive background transparency levels based on the luminance of the outside environment.

CCS CONCEPTS

• **Human-centered computing** → *Mixed / augmented reality*; *Text input*; *Interactive systems and tools*; *Interaction design*.

KEYWORDS

visual aesthetics, dark mode, automated driving, chat application, windshield display, user study

1 INTRODUCTION

While a number of technical challenges regarding automated vehicles has been resolved recently, many of the proposed advantages of these vehicles (such as improved traffic flow, increased safety, etc.) will only become true if they are accepted and used by drivers. With internal vehicular interfaces transitioning to (non-driving) passengers ([12], [14]), new possibilities with regard to human machine interfaces (HMI) and the interaction between drivers or passengers and the vehicle emerge. At highly automated driving (SAE level 3 [6]), the driving task is largely no longer performed by the driver, thereby transforming the vehicle into a new mobile

living and working space [24]. This circumstance can be used for work- or social media related activities, such as writing text messages [26]. Windshield displays (WSDs), considered as the big siblings of head-up displays (HUDs), are one of these emerging vehicular interfaces [9]. However, the usage of WSD applications is quite different from desktop and mobile applications (e.g. contrast, lack of touch interfaces, static/dynamic environment). One of the arising challenges is to display an intuitive user interface whose features are tailored to the driver's needs. A solution would be a personalized interface which is much easier to realize when its elements are virtual rather than physical (i.e., augmented reality content on a display vs physical knobs and buttons). Floating 2D or 3D augmented reality (AR) objects are a promising approach towards the realization of such a versatile interface. With the recent developments in the desktop domain (Windows 10 version 1809, macOS Mojave) and announcements in the mobile domain (Android Q, iOS 13), a "dark mode", i.e. white/bright text on black/dark background, can be a viable presentation style for windshield displays. WSDs offer a number of advantages: They eliminate physical and visual clutter in the center console and as result enable gesture-based interaction [23]. Furthermore, WSDs can provide a single interface for all in-vehicle infotainment systems [7]. Although the potential of WSDs has been highlighted, e.g. in [8], [33], little research was conducted to evaluate the role of transparency and color of WSD applications. In this work, we present results of a user study evaluating user preferences of a WSD chat application regarding the before-mentioned characteristics.

2 RELATED WORK

Various studies have shown the benefits of HUDs or WSDs for the presentation of information related to the operation of the vehicle itself. For example, Sojourmer et al. [28] found that subjects using a driving simulator that featured an HUD speedometer reacted significantly faster to salient cues in the driving scene versus a dashboard-mounted speedometer. Burnett [4] investigated the use of navigational cues and found that participants made fewer wrong turns when an arrow graphic and contextual information about the surrounding roads was displayed on a HUD versus on a head-down display (HDD).

However, little research has been done on drivers' ability to process and interact with information not immediately or directly related to vehicle operation, such as navigating a music player or typing in a chat application, when this information is presented via WSDs.

The use and relevancy of transparency in user interfaces differs in the desktop and mobile domain, from its role for windshield displays (e.g., [7], [18]). For example, it possible to augment objects outside the vehicle, e.g. for visualizing points of interest, such as nearby restaurants, but also potential dangers. [19]

Tsimhoni et al. [31] determined the best position for presenting short text on a full-windshield HUD, evaluated in terms of driving performance and workload. They found that message locations within 5Âř of a straight-ahead gaze resulted in the best performance and were preferred by subjects. However, these conclusions were obtained based on very brief words (names). Our work aims to determine whether such findings hold for a larger interactive chat application on the windshield display.

Weinberg et al. [32] conducted a driving simulator experiment, investigating two potential alternatives to head down displays for presenting textual lists. Subjects performed a series of street name finding tasks using each of three system variants: one with a HDD, one with a HUD, and one with only an auditory display. They found that, while the auditory display had the least impact on driving performance and mental load, the HUD variant had a low impact on mental load and received the highest scores in user satisfaction.

AR WSDs still face challenges such as change blindness [21] (i.e., information in the driver's field of view that is missed due to superimposed content) or visual clutter [11]. However, AR technologies are still evolving and will become more sophisticated in the future. AR content can be utilized to keep a driver's visual attention on the road by reducing or even eliminating glances between the primary driving task and other activities (looking at the dashboard, operating the center console etc.) [27].

Therefore, information visualization plays an important role also for windshield displays. The placement, size and content types of windows, such as warnings, work-related content or entertainment content, have already been investigated (e.g., [9], [22]). However, research still has to figure out the role of transparency for windshield displays, especially considering the many use cases, such as work vs leisure trip, conditionally vs fully automated driving etc. For work-related tasks such as reading emails in highly automated vehicles, a fully transparent window could distract the driver by not occluding the outside vicinity. In contrast, drivers might prefer watching a video on the WSD in fully opaque mode.

Considering the issues discussed above motivated this paper, and a study investigating the impact of the position, transparency and text of interactive augmented reality content on windshield displays does, to our best knowledge, not yet exist. Therefore, we created two experiments in simulated situations since real implementations of windshield displays are still missing.

Figure 2: The study setting.

3 DESIGN AND IMPLEMENTATION

We designed an experiment that enables users to perform a text chat on a WSD. This application can be seen as placeholder for other text intensive activities such as writing emails or reading a newspaper article on the WSD [25]. We choose to conduct our evaluation on a two-dimensional display, since (1) mixed-display distances can have a negative impact on performance [29], and (2) participants do not seem to prefer continuous depth on WSDs [9].

We developed a chat client and server application in Java. The graphical user interface was implemented using Java Swing. We used a high resolution video displayed on a 55" screen to simulate the automated driving scenario. The video was recorded with a GoPro HERO5 Black action camera, and was positioned to show the entire windshield from the driver's point of view. The video gives the impression of being driven around in a small city. The video included sounds (engine, turn signal sound, ambient noise). To give our participants a more immersive experience, we placed a Logitech G27 steering wheel in front of them, however, we did not assign any functionality to the steering wheel. Furthermore, we placed a keyboard in front of the steering wheel in order for the participants to chat with the experimenter. The chat server and experimenter's chat client instance were running on one computer, while the participant's chat client was used on a different computer. The chat client window was overlaid with the video running in the background. The setup was presented to participants in fullscreen/borderless mode on a 55" flat screen monitor with a resolution of 2560x1600px, representing the windshield display (see Figure 2). This type of AR content is referred to as car-stabilized/screen-fixed (e.g., [16], [10]).

4 EVALUATION

Our goal was to investigate characteristics of a real-world application, a chat application, on a windshield display. We were interested in the location of the chat window, foreground and background colors, and transparency. Additionally, it was important to us to see how drivers would prefer such an application to be presented and interact with it in an automated vehicle.

Method and Research Questions

We chose to simulate an SAE level 3 driving scenario. The vehicle is responsible for the driving operation, which means that the driver is no longer required to monitor the vehicle, yet must be able to assume control when requested to do so by the vehicle. The reasoning behind our decision to simulate highly automated driving is that windshield displays are a promising instrument for enabling the transition from manual driving to system-controlled driving [8]. Due to its variable display options, a WSD can support the driver during manual driving (e.g., [5]) as well as act as a user interface for work or entertainment related activities during autonomous driving (e.g., [22]). In addition, it can be used for the successful execution of a take-over scenario (e.g., [13], [20]), which describes the transition of the driving task from the vehicle back to the driver.

We formulated four research questions:

- **RQ1:** Which background transparency levels are suitable for text-related activities (i.e., reading and writing text)?
- **RQ2:** Do participants prefer the nowadays popular dark mode, i.e. white text on black background, or vice versa?
- **RQ3:** Which location on the windshield display is preferred for text-related activities (i.e., driver side vs. passenger side)?
- **RQ4:** Do users want to have control over window properties such as size, colors and transparency or should the system determine suitable parameters?

5 PILOT STUDY

First, we conducted a pilot study to verify the tasks, the choice of hypotheses, the study structure, and to identify bugs. For the experiment, we came up with five presentation styles for presenting the chat window and its content to our subjects:

- white text/black background (0% transparency)
- black text/white background (0% transparency)
- white text (100% transparency)
- black text (100% transparency)
- self-chosen text and background color (black vs. white), and transparency (between 0% and 100%)

We used black and white as text and background colors which provide better legibility, according to Lalomia et al. [15]. Riegler et al. [22] found that work-, entertainment- and social media-related content is preferred to be displayed in the driver's field of view or above the center console in highly automated driving. This is also the case for displaying short text messages [30]. However, we also wanted to see if participants would find the chat window being on the passenger side appealing. Furthermore, we chose a simple presentation style of the chat, contrary to today's popular dialog blobs of messaging applications, because we wanted participants to focus on the used colors and transparency rather than the layout and animations within the chat window. Therefore, we designed the user study as 3×2 (text/background color/transparency $\times$ window position) within-subject counterbalanced design.

Procedure

First, participants had to complete a short questionnaire assessing demographic data. We explained the concept of highly automated driving and noted that the participant would have to actively take control of the steering wheel during the experiment in case of a take over situation (such as an accident). We further explained the concept of a windshield display. Participants were presented the video of the automated drive, with the chat window being in the foreground either on the driver or on the passenger side. Participants were asked to retype the text presented on the chat window. We decided to let participants re-type the presented text because this activity does not require much cognitive demand in comparison to answering (personal) questions, for example. Further, demographic data and survey questions related to WSDs were obtained. The text consisted of a semantically correct sentence, between 8 and 15 words. After entering the text, the participant had to press the Enter key on the keyboard, and the experimenter entered the next phrase. Typos were allowed and it was possible for the participants to correct them.

For each participant, both locations were tested as well as different scenarios, i.e., white text on black background and black text on white background with varying transparency (either 0% or 100%). For each presentation style, five sentences had to be re-typed (same for all participants). After these pre-defined presentation styles, we asked participants to set their ideal setup using a transparency slider from 0% to 100% as well as text and background color (black/white) and location (driver/passenger side). Afterwards, we asked the participants to evaluate the different presentation styles by assigning 100 points to the options that were performed. Additionally, our experimenters were constantly taking notes

about the participants and asked them about potential improvements. The experiment lasted approximately 25 minutes for each participant.

Preliminary Results

In total, 10 participants (7 male, 3 female) between 22 and 55 ($Mean = 35$, $SD = 11.8$) years participated in the experiment (all possessing a valid driver's license). In the following, we present a detailed investigation of the obtained results.

6 out of the 10 participants preferred the fully transparent window background. Additionally, when self-assigning a transparency level for the window background, participants chose a mean transparency level of 31.5%, ($SD = 21.7$%), i.e. an opacity level of 68.5%.

When presented the pre-defined presentation styles, participants strongly preferred white text on black background ("dark mode"). When the chat application was located on the driver side, the dark mode appearance received a mean score of 60 points ($SD = 22.7$) and black text on white background 40 points ($SD = 22.7$). We note that these results were obtained from university students and staff of a computer science department. However, with recent and announced modifications of popular operating systems (Windows 10 version 1809, macOS Mojave, Android Q, iOS 13), dark modes are becoming more popular and visible to the general public.

Furthermore, subjects strongly preferred the chat application to be on the driver side instead of the passenger side, which is consistent with [22]. 9 out of the 10 participants favored the text on the driver side.

In addition, our observations showed that participants on the one hand chose transparency levels not defined by default, and that automatic adaptation of background transparency would be desired if available.

The post-study interview about potential improvements to the chat application on the WSD revealed that 7 out of the 10 participants would like some kind of adaptive window background which depends on the outside-the-vehicle scenery. 2 participants further stated that they would like the used colors to depend on their mood. While research has been conducted in this field [17], a practical use should further be investigated, especially considering potential cultural issues [2]. Some participants further noted that a chat application on the WSD, such as WhatsApp, might lead to some privacy concerns; i.e., they would not want friends or strangers to see their chat history. Regarding the shape of content windows on WSDs in general, 3 participants stated they could imagine shapes other than rectangles, with circle being chosen 2 times and freehand-drawn shape once.

6 MAIN STUDY

Based on these preliminary results, we further expanded on our research. The most important modification to the

chat application was the introduction of an adaptive window background transparency based on the luminosity of the surrounding environment.

Before calculating the transparency, we first have to determine the relative luminance of the surrounding environment, i.e., everything "inside" the windshield display, for a specific point in time. Therefore, we need to extract the red (R), green (G) and blue (B) components of the screenshot of the video. The relative luminance Y is calculated as follows, and takes values between 0 (black) and 100 (white):

$$Y = 0.2126R + 0.7152G + 0.0722B \qquad (1)$$

Formula 1 reflects the luminosity function, based on human subjective perception, where green light contributes the most to the intensity perceived by humans, and blue light the least [1].

In order to map the calculated luminance to a transparency level, we found that for the dark mode presentation style, a high luminance should result in low background transparency (high opacity), in order to increase the legibility of the white text. The transparency also takes values between 0 (fully opaque) and 100 (fully transparent).

After calculating the new transparency value, the chat window background must be updated. In order to avoid flickering and reading disturbances, we implemented a linear fade animation transition between the old transparency value and the new one. We defined the update interval to be one second, i.e., the luminance and subsequent transparency calculation and fade animation were repeated and executed every second.

Another aspect for investigation which we included in the main study was the changing environment and scene complexity (i.e., urban vs. rural driving). Therefore, we added a new video, giving the impression of driving on a rural road, in addition to the pilot study video of driving in a city. Both videos were taken during daytime, but included brighter and darker areas which resulted in distinct changes of the adaptive window background transparency. The lighting in the lab was setup in a way to reflect the lighting in the videos.

Procedure

In an analogous manner as in the pilot study, the study coordinator introduced the concept of windshield displays and automated driving, as well as the chat application. Participants were asked to complete a demographic questionnaire. The next 20 minutes formed the core of the study, where subjects operated the chat application in two possible dark modes: static background transparency (S) of 31.5%, which was the preferred transparency level in the pilot study, and adaptive background transparency (A). The scenery (city, rural) was also changed for each drive. After each of the two

chat tasks, a short questionnaire about the transparency and legibility had to be completed, as well as the technology acceptance questionnaire. For the last five minutes of the study, participants were asked to express their personal opinion and attitude towards the system.

In contrast to the pilot study, where we aimed to assess general settings for the chat application, the subjects were instructed to pay attention to the outside environment, such as pedestrians or events which might appear in both (city, rural) scenarios. We were interested in finding out the number of pedestrians participants would take note of during the simulated drive. We chose a counterbalanced 2×2 (city/rural scene × adaptive/static dark mode) within-subject study design, i.e. half the subjects would start with the fixed background chat window, while the others started with the adaptive background design. Similarly to the pilot study, participants had to re-type the sentences specified by the interviewer. For each task, 15 sentences were required to be repeated in the chat window. After each chat task, subjects were asked to define both the quality of the chat window's background transparency as well as the legibility of the text. This was specified by drawing a marker on the line. The farther to the right the marker was drawn, the better participant assessed the see-through quality or readability of the chat window. After the second task, participants were not given access to the prior assessment. Additionally, a technology acceptance questionnaire (TAM) had to be completed, assessing the usefulness, ease of use, attractiveness, trust and intent of the WSD chat application. Furthermore, subjects were asked to specify how many pedestrians they counted during the task execution. After the first task, we changed the scene video (city, rural). Upon the completion of both tasks, the subjects were asked to compare both the transparency and legibility assessments of both tasks and were given the chance to re-adjust their markers. If chosen to do so, subjects were asked for reasons for changing their previously drawn markers. The study lasted about 35 minutes for each participant.

7 RESULTS

We recruited 20 additional participants (13 male, 7 female) between 20 and 31 ($Mean = 23.8$, $SD = 2.4$) years with no knowledge of the project from the general population of our university, using mailing lists and posted flyers. All subjects were in possession of a valid driver's license. In terms of annual mileage, 5 participants drove less than 1000km and (25%) 9 participants between 1000km and 10000km (45%). The remaining 6 respondents reported a higher mileage (30%). Furthermore, all participants were familiar with chat applications and mentioned using them in their daily life. Participants had normal or corrected to normal vision. In this single-session, within-subject lab study, informed consent was obtained.

TAM Variable	Items	Cronbach's α
PU	3	.859
PEOU	3	.819
ATT	3	.713
Trust	3	.913
Intent	1	-
All applied TAM variables	13	.848

Table 1: Overview of Cronbach's α for the TAM.

	Median	
TAM Variable	S	A
PU	5	6
PEOU	7	7
ATT	6	6
Trust	5	6
Intent	5	6

Table 2: Overview of the medians of the TAM for the static (S) and adaptive (A) background transparency conditions.

We analyzed the Technology Acceptance Model questionnaire, the questionnaire assessing the perceived quality of background transparency and legibility of the text, as well as error rates regarding the number of pedestrians counted.

Technology Acceptance Model

All variables were completed by subjects on a 7-point Likert scale (1 = "fully disagree", 7 = "fully agree"). We evaluated the variables Perceived Usefulness (PU), Perceived Ease of Use (PEOU), Attractiveness (ATT), Intent of the system, and Trust in the system.

We first determined the validity of our results using Cronbach's α (see Table 1). The results confirm our data to be valid for further evaluation.

We calculated the medians for the TAM sub scales because of the ordinal measurement of Likert scale items [3]. Considering the medians of the evaluated TAM sub scales we can see that condition A (adaptive window background) received better ratings than condition S (static background) in the scales perceived usability (PU), Trust and Intent, see Table 2. Since the task was writing text in a chat application, we expected the PEOU scale to be very high, for both conditions.

Perceived Quality of Transparency and Legibility of the Text

Based on the two chat tasks, we determined the subjective preferences for the chat window background transparency and the legibility of the text. Subjects gave higher ratings to the adaptive setting (background transparency: $Mean =$
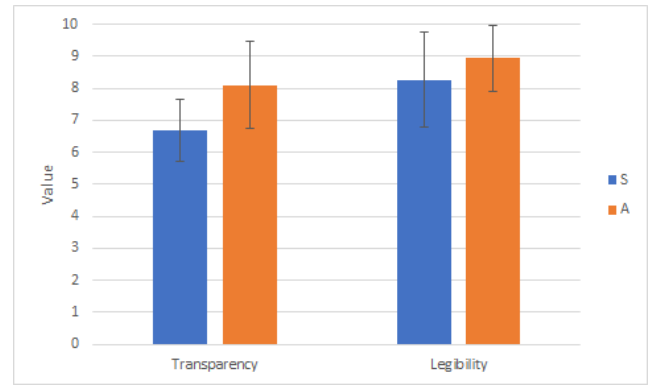
Figure 3: Mean subjective values for the background transparency and legibility of the text for the conditions S and A according to the participants.

$8.265, SD = 1.487$; text legibility: $Mean = 8.935, SD = 1.037$) compared to the static one (background transparency: $Mean = 6.7, SD = .975$; text legibility: $Mean = 8.105, SD = 1.37$), see Figure 3. A two-tailed paired t-test between the ratings for the two conditions shows statistically significant differences ($p = .020$ for the background transparency, $p = .011$ for the legibility of the text), $P \leq .05$.

Error Rates

We further took note of the counted pedestrians as specified by the subjects at the end of each tasks and calculated the error rates. The mean error rate for condition S was .138 ($SD = .172$), and for condition A .05 ($SD = .103$). The difference is statistically significant ($p = .005$) using a two-tailed paired t-test ($P \leq .05$).

8 DISCUSSION

Regarding **RQ1**, participants preferred transparent window backgrounds as opposed to fully opaque ones. Additionally, when self-assigning a transparency level for the window background, participants chose a mean transparency level of 31.5%. However, when given the choice between a static transparency level and an adaptive one, based on the surrounding luminance of the environment, subjects strongly preferred the adaptive one, according to the TAM and custom variables we processed.

The results in regard to the preferred text and background color combination were mixed (**RQ2**). When presented the pre-defined presentation styles, participants favored white text on black background. This is consistent with dark backgrounds gaining popularity in recent years with the introduction of "dark modes" in operating systems and visual applications.

Answering **RQ3**, participants strongly preferred the chat

application to be on the driver side instead of the passenger side, which is consistent with Riegler et al.[22]. 9 out of the 10 participants favored the text on the driver side.

Regarding **RQ4**, we can say that users on the one hand chose transparency levels not defined by default, however, qualitative feedback shows the desire for automatic adaptation of background transparency. When presented with both static and adaptive transparency levels, subjects strongly preferred the latter one. Additionally, error rates regarding the number of counted pedestrians during the simulated drive were lower when the chat application was presented in the adaptive transparency mode.

We conclude that transparent dark mode in WSD applications may have the same high potential as in desktop and mobile applications. Additional brightness adaptation shows promising results in subjective perception. These measures could further boost handover performance as the adaptive window background provides the driver with a smoothing see-through experience.

9 LIMITATIONS

We are aware that our experiment has some limitations. First, the study was executed as lab experiment in a static environment and 2D monitor. Preferences might differ in a real driving scene. Second, we did not include concrete takeover scenarios during the simulated drive. We instructed the subjects to be aware of the driving situation, however, we refrained from including emergency events as we intend to investigate take-over scenarios with WSD content in future studies on a more quantitative scale. For instance, we intend to further investigate the adaptive dark mode in a more immersive virtual reality environment with a higher degree of control over lighting conditions, and in conjunction with physiological measurements to examine stress levels. Furthermore, we assumed that the driver sits in the vehicle without any other passengers. In situations where the chat window could be seen by other passengers might arise privacy concerns and therefore affect preferences towards WSDs. Another limitation exists in the selected participants. In our studies, mostly tech-savvy university students and staff participated. The general population, especially elderly drivers, might have different requirements.

10 CONCLUSION AND FUTURE WORK

In this work, we investigated the role of text and background color combinations in conjunction with different transparency levels. We created a chat application and placed it on a simulated windshield display using a flat screen monitor. Furthermore, we assumed highly automated driving and drivers want to transition from the primary driving task to other activities, such as text messaging. Our initial results indicated preferences for a dark mode and the window location on the driver side. Based on the results and responses from our pilot study, we further investigated color and adaptive transparency concepts for windshield displays. We created an adaptive view which automatically changed the window transparency based on the luminance of the surrounding environment. A high outside luminance was reflected in a more opaque background window for the benefit of increased legibility of the text. In contrast, when driving through a darker/shadowy area, the window background of the chat application would automatically change to be more transparent.

For future work, we intend to create an entire view management of WSDs (presenting information) as well as interaction management (interacting with information), where the presented dark mode is integrated. For instance, the physical keyboard could be replaced with an AR keyboard operated by pointing gestures. Furthermore, privacy issues related to WSDs are definitely worth exploring in greater detail.

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