Automotive Head-Up Displays (HUDs) are Not yet Saving your Life: A Literature Review of the Human-Technology Interaction Challenges of HUDs

Bachelor Thesis Artificial Intelligence - 7.5 ECTS

Dorien Juch, 5636949
Faculty of Humanities, Utrecht University
Artificial Intelligence
(n.d.juch@students.uu.nl)

Supervisor: dr. Stella Donker
(s.f.donker@uu.nl)
Second reader: dr. Erik Stei
(e.v.stei@uu.nl)

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Abstract

HUDs have the potential to increase driving performance, however, the display design of HUDs often relies on common wisdom instead of scientific support. Visual clutter and salient symbols in HUD displays can visually distract the driver, which can reduce driving performance. In this literature review, the purpose is to determine how the human-technology interaction of HUDs can be optimized by increasing observability and minimizing visual distraction from visual clutter and saliency. Findings were that visual clutter can possibly be minimized by using up to four symbols and correctly placing different types of symbology within the view of the driver. To prevent unwanted visual saliency to occur, a visual enhancement system may not be used or solely when correctly adjusted. Additionally, saliency can be adjusted to the driver's abilities by using the right enhancement-contrast ratios and preferably not making use of flashing symbols. Regarding the findings of the reviewed literature, an interface proposal is created to provide guidelines for future HUD display designs.

Contents

1 Introduction

Nowadays, you do not need to grab that large route map to reach your destination in the fastest way. You just enter the address into the navigation system in your car. We are probably all familiar with the conventional navigation systems located inside the console of the car. New smart car navigation technologies like head-up displays (HUDs) are emerging that are capable of presenting large amounts of information right in front of the eyes of the driver. Imagine a future in which all information (such as driving speed, navigation information and messages) is projected on the car window right in front of you. This seems handy at first sight, but does this system actually enhance the abilities of the driver? Future HUD technologies must adapt to humans in order to improve the human-technology interaction. As Raisamo et al. (2019) state it: “In the past, humans had to adapt to computers. In the future, computers will adapt to humans.”

First, zooming in on these HUD systems: they project a virtual image on a transparent display or glass window which is located inside the viewpoint of the driver (Ablaßmeier et al., 2007). This enables the user to view information with the head positioned “up” instead of looking down at a head-down display (HDD) in the console. The automotive industry is increasingly making use of augmented reality technologies trying to make driving safer and more convenient (Kim & Gabbard, 2018). The purpose of the HUD is to reduce the amount of time that is needed to process display information (Ward & Parkes, 1994). However, these new in-vehicle technologies often do not rely on scientific support, but rather on using common wisdom (Sharfi & Shinar, 2014). HUDs enable the driver to look forward and so it is assumed that the user can pay attention to the road, therefore HUDs would improve driving safety. However, several studies have reported possible negative consequences from using HUDs such as visual salience (Sharfi & Shinar, 2014), frequent changes in the HUD image (Wolffsohn, McBrien, Edgar, & Stout, 1998), and visual clutter (Donkor & Burnett, 2012). These factors can possibly cause the driver to get distracted.

Not surprisingly, distraction is increasingly recognized as an important risk factor in traffic (Stelling & Hagenzieker, 2012). Due to the continuous distribution of electronic devices in traffic, such as navigation systems, the problem of distraction is becoming even worse. Distraction can be defined as “misplaced” attention. It shifts the driver's attention away from the actions that are critical to perform the driving task safely (Stelling & Hagenzieker, 2012). Operating a navigation system can cause distraction, which results in less attention being paid to the surrounding traffic (SWOV, 2018). There exist several types of distraction among which visual, cognitive, physical and auditory distraction. Especially visual distraction can play a big role when operating an automotive HUD since the technologies are capable of displaying an overload of information with salient symbols. These aspects may command too much of the user's visual attention, resulting in worsened driving performance. Therefore, it is of much importance to limit these visual distractions from occurring when using HUD interfaces as this will increase the "eyes-on-the-road time".

The main question of this thesis is as follows: How can human-technology interaction of HUDs be optimized by increasing observability and minimizing visual distraction from visual clutter and saliency? The aim is to reduce the visual distraction of HUDs and increase observability in such a way that the system enhances human abilities, which will result in an increased "eyes-on-the-road" time. This requires a human-centred approach in which the system will guide the user and support rather than constrain the human's abilities (Charissis & Papanastasiou, 2010). More specifically, the focus of this thesis will be on the factors that can make current HUD displays visually distracting. Visual saliency of HUD symbols and visual clutter are two mainly appearing visually distracting factors in HUDs (Sharfi & Shinar, 2014; Donkor & Burnett, 2012). A definition of visual clutter is given by Gish and Staplin (1995): "The extent to which there are features in a visual scene (either on a HUD or in the external scene) that may interfere with aspects of the primary task." Additionally, the term visual saliency is used here to refer to: "The distinct subjective perceptual quality which makes some items in the world stand out from their neighbours and immediately grab our attention" (Itti, 2007). The focus will be on these two topics as these have a major impact on the observability of HUDs and the focus on the road. A literature study is performed and starts off with a brief explanation of HUD systems and the varieties between displays. After that, the effects of visual clutter and visual saliency on HUDs will be investigated. For each distracting factor, a solution is tried to be found that could be implemented in future HUD displays. The goal is to take these findings together to create a HUD interface proposal that is both observable and minimizes visual distraction coming from visual clutter and saliency. Since the most current design challenges are included in this study, the proposed interface can act as an accurate contribution to observable and non-distracting HUD displays in the future.

1.1 Relevance in Artificial Intelligence

With upcoming new in-vehicle technologies it is necessary to provide scientific information in order for these technologies to be correctly implemented and enhance road safety. HUDs can potentially increase road safety, but several studies found that there can be negative effects of HUDs when it comes to the rate of distraction (Sharfi & Shinar, 2014; Wolffsohn, McBrien, Edgar, & Stout, 1998; Donkor & Burnett, 2012). When optimizing HUD symbols in order to be observable and limit visual distraction, it has the potential to increase driver performance and with that also road safety. In this way, a contribution can be made to the human-technology interaction: the HUD can be optimized for humans to use. When the HUD image is adjusted to its user, the driver will be able to perform the driving task safer. A successful human-centred interface should enhance human actions, senses and judgment of the driving task (Charissis & Papanastasiou, 2010). This thesis will contribute to the interface design challenges that are faced within this human-technology interaction. By providing the right amount of information through clever designed HUD interfaces it could improve the driver's response time and enhance the understanding of the vehicle's surroundings (Charissis & Papanastasiou, 2010).

2 Background Information

2.1 The HUD System

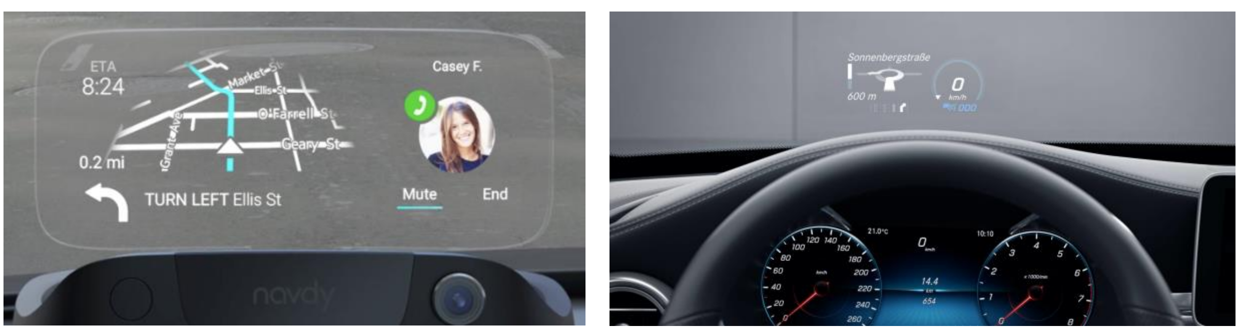
The aim of this chapter is to provide some background information in order to understand what a HUD system is and what varieties there exist between HUD displays. In this way, a small insight will be given of what already exists in this market and what possibly makes HUD displays distracting. A HUD is a system that projects a digital image on a window or glass screen in front of the user and projects driving information like speed and navigational instructions. Technological devices like the conventional head-down display (HDD) systems, radios and mobile phones - that display information that is not primarily needed to execute the driving task - can cause drivers to shift their gaze off the road (Ward & Parkes, 1994). The idea behind HUDs is to reduce re-accommodation time of the observer's eyes. The HUD image can be collimated in a further distance inside the visual field, enabling a reduction in accommodation time of the eyes compared to HDDs that are located in the console of the car. The displayed symbols from the HUD are more integrated in the vision, enabling the driver to perceive information faster from HUDs than from HDDs. However, as discussed before, HUDs can still fail in being optimally observable by humans as they can be visually distracting by visual clutter and saliency. Before zooming in on this problem in the next sections of this thesis, first a short sum up the different versions of HUDs nowadays.

HUDs have been widely used in (military) aviation already and are yet to find their way being applied into road-based vehicles on a large scale (Burnett, 2019). There are several different applications of HUDs: 1) In-car HUDs: this type of HUD is built into the car. Car brands like Volkswagen, Audi and several others provide the option to buy built-in car HUDs; 2) HUD apps: there are apps providing HUD functions that can be downloaded on a phone. When turning on the app, setting the screen bright and placing the phone in front of the driver, it reflects the image of the driver's speed and navigational information on the windshield; 3) Portable HUDs: these are individual devices that can be placed near the windshield, consisting of a small box and a transparent glass that reflects the HUD interface. Some of these applications might be designed to minimize visual, cognitive and physical distraction, but some of them do not prioritize these elements. When there is no focus on minimizing distraction, the HUD interface can become less safe in terms of car safety.

2.2 Interface Variations

Here are some examples of current HUD interfaces to see in what way they can be visually cluttered and salient. A first example is the Navdy HUD interface (2017) (fig. 1). The company states the following about their HUD: “Drive safer. Stay connected.”. The HUD enables one to view receiving calls, text messages and to adjust the music. Especially messages contain many textual information, which is likely to visually interfere with the primary driving task when presented inside the view of the driver. This suggests that the Navdy HUD likely contains a visually cluttered interface. In addition, this Navdy system uses a bright contrasting interface, which may be visually salient and drag visual attention from the driver. This makes their claim “drive safer” slightly questionable and “staying connected” should not be the priority when driving a car. The possibility to stay connected might be appreciated by many users, but by enabling the user to read incoming messages, the driver will be more visually distracted than is needed. This HUD display, therefore, seems to contain both visual clutter and saliency.

Fig. 1 - Navdy HUD interface (Navdy, 2017) (left) and the Mercedes-Benz HUD interface (right) (Mercedes-Benz, n.d.).



A second example is the build-in car HUD from Mercedes (fig. 1). The interface of this HUD looks somewhat simpler designed than Navdy’s interface, as there are fewer symbols and less salient colours. However, the display is placed in the middle of the view, which may cause the display to interfere with the central view of the driver. Superimposed symbology that is placed near the outside scene information can attract the visual attention of users (Foyle et al., 2001). Thus, the superimposed symbology from this HUD may cause a greater amount of visual clutter in the driving scene.

Another example is the in-car HUD from car company Volvo, which shows information relating to speed, cruise control functions, navigation and warnings. This HUD does not display text-messages, however, it does show incoming calls in the interface allowing the driver to pick up calls hands-free. Hands-free calling might take away the physical and visual distraction compared to handheld use of a phone, but the cognitive distraction is still equally big (Slootmans, 2015). Warning symbols are shown temporarily in the head-up display, which consists of flashing symbols in colours like red or orange. These flashing symbols are likely to catch the driver's visual attention faster than other non-flashing symbols (Crawford, 1962). The use of flashing symbols in HUDs, therefore, causes visual saliency.

Thus, there are different HUD interface designs which sometimes take both driving safety and connectivity as priorities. However, when prioritizing connectivity, incoming calls and messages are displayed into the HUD interface. Text messages contain a great number of textual symbols and cause a visually cluttered HUD image. It is clear that the number of symbols and the positioning of the display can interfere with the primary driving task, resulting in clutter. Additionally, contrast ratios and flashing lights can contribute to a visually salient HUD image. These findings suggest that current HUD images are not optimally reducing visual distraction. Factors like the number of symbols, symbol positioning, contrast ratios and flashing symbols should be looked at carefully in order to enhance observability.

3 Visually Distracting Factors Appearing in HUDs

3.2 Visual Clutter in HUDs

Now, the two main factors in HUD interfaces will be discussed that possibly reduce observability or visually distract the driver: visual clutter and visual saliency. Starting off with visual clutter. Clutter in HUD displays can arise when for example the display contains a great number of different symbols or when symbols are placed too close towards the centre of the view. When features interfere with the viewing scene, the complexity of the driving environment increases. A complex situational environment can result in worsened driving performance. For example, Lee and Triggs (1976) found that drivers who performed a peripheral detection task performed worse in detecting traffic lights in a complex scene compared to a simple scene. In addition, Beck, Levin and Angelone (2007) found that drivers are less likely to detect changes in the environment when these are complex and crowded. It follows that whenever clutter occurs inside the view of the driver, the driving environment becomes more complex and distracts the driver from the primary task. These negative effects can be due to both visual and cognitive distraction that occurs when visual clutter arises (Ward & Parkes, 1995; Donkor & Burnett 2012).

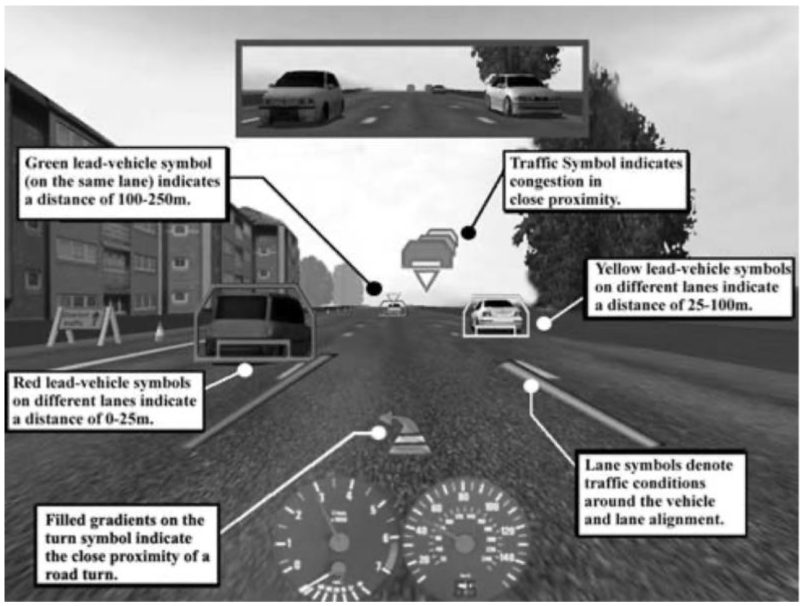
Moreover, it is important to keep the HUD display information simple to minimize visual clutter. A secondary task, like viewing a HUD display, can possibly increase the workload of the driver. The driving task itself already consists of multiple subtasks, so it is not preferable to add a fairly complex task to this. If visual clutter from HUDs can be minimized, it will reduce the complexity of the HUD viewing task and also reduce visual and cognitive distraction due to clutter. There are at least two different aspects that contribute to the amount of visual clutter caused by HUDs: the number of symbols projected in a certain area and the placement of the symbols within the view.

First, the number of symbols in a HUD display can cause clutter as they interfere with aspects of the primary task. The driver has to shift his eyes and attention from the road to the HUD display for a relatively long time, as scanning is needed to find the required symbol between all other symbols. In an experiment performed by Donkor and Burnett (2012) participants were asked to respond to peripheral detection tasks. As the number of symbols of the HUD increased, the response time on the tasks increased and accuracy on performance decreased. The clearest negative effect on distraction arose when the HUD image progressed from four symbols to seven symbols. These results indicate that the HUD image should preferably not contain more than four distinct symbols to minimize the amount of visual distraction and cognitive capture. However, when the design of the symbols is optimized according to Donkor and Burnett (2012) the HUD image may include a maximum of five to six symbols.

Second, to prevent visual clutter from occurring the positioning of the symbols inside the HUD interface has to be chosen carefully. Symbols that are positioned in the middle of the central vision can cause the driver to take his eyes off the road, creating visual distraction. Inuzuka, Osumi and Shinkai (1991) found that any symbology placed within a 5-degree radius of the central vision would be “annoying” to drivers. However, Gish and Staplin (1995) state that it may be the case that this preference only holds for this type of information. The preference for not having any speed information inside the central vision may be due to the fact that viewing speed information is not a priority when performing a driving task. Therefore, this suggests it would be best if non-conformal symbology (e.g. digital or analogue speedometers) of HUD interfaces is located in the peripheral vision. Foyle et al. (2001) found that tunnelling of visual attention can be prevented by placing HUD symbology at least 8 degrees outside of the central vision of the driver. However, projecting symbols inside the central vision that highlight the contouring of external objects, may be more suitable for the driver's needs. This is called conformal symbology; these symbols enhance external targets which gives the observer the perception that the symbology is actually part of the external scene

(Gish & Staplin, 1995). Since these symbols may look like they are part of the environment, it could be a preference to use solely conformal symbology inside the central vision of the observer. Charissis and Papanastasiou (2010) designed a HUD interface where conformal symbology was used to highlight surrounding vehicles (fig 2). Drivers participated in an experiment with this HUD interface, resulting in 62.5% of the drivers ranking a red lead-vehicle warning as “extremely helpful” and 35% as “very helpful”.

Fig. 2 - Interface proposal from Charissis and Papanastasiou (2010).



The red lead-vehicle warning acts as a mechanism to avoid collisions that warns the driver that a vehicle is coming up close. However, this may be perceived as useful to the drivers, it is not proven that conformal symbology increases the performance of drivers when comparing to HUDs that do not use symbology inside the central view. Taking this information together, there are two main things that may increase observability and decrease visual clutter: 1) non-conformal symbology should be placed at least 8 degrees out of the central view of the driver; 2) conformal symbology might be the only acceptable type of symbology inside the central view, however, it is not proved to increase the performance of drivers if compared to no use of symbols in the central view at all.

3.2 Visual Salience in HUDs

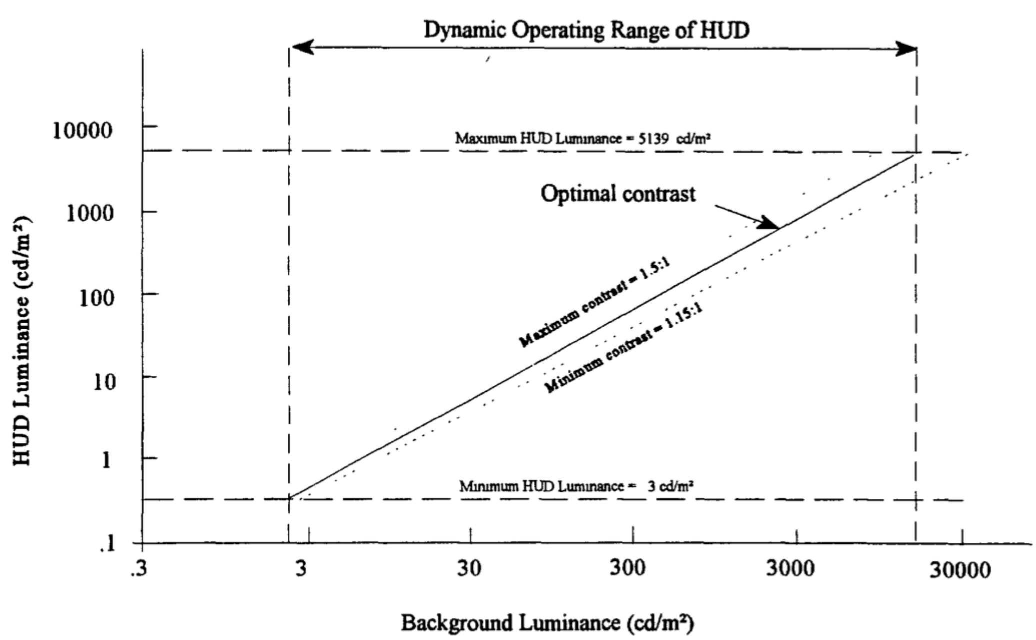
Besides visual clutter, visual saliency in HUD interfaces can cause visual distraction. However, when symbols are not salient at all, they may not be observed by the driver. So the aim is to find a balance in good observable but not too salient symbols. The attention of humans is attracted to stimuli that are visually salient and the more salient an item is, the faster the attention is dragged to this item. The perceived saliency depends on the properties of the item within its environment. When developing a HUD display the saliency of the symbols has to be chosen carefully, because it is not preferable for all the symbols inside the HUD interface to be so salient that they immediately attract attention above obstacles on the road that are less salient. However, for some symbols that require direct attention like warning signals, saliency might be useful.

Visual saliency plays a role in HUD displays in different scenarios, among which: the use of a Visibility Enhancement System (VES), flashing lights, high enhancement-contrast ratios and a night vision thermal camera. Sharfi and Shinar (2014) investigated the effect that VES has on drivers. VES is a system that enhances visual elements in the driving scene like the lines of the road and approaching cars. Projected highlighted elements can be visually salient and drag more attention than unhighlighted objects inside the driving environment. Sharfi and Shinar (2014) found that a VES, possibly reduces driving safety as the enhancing of visual elements is likely to be too salient. While drivers used VES they started to assume that the visibility of obstacles on the road was also improved (Sharfi & Shinar, 2014). The current enhancement systems selectively enhance elements, meaning that some elements are automatically being de-selected. So the surrounding cars and roadway may be highlighted as other objects are not. Especially while driving under low visibility conditions, the use of VES is critically reducing the driving performance (Sharfi & Shinar, 2014). These findings suggest that the use of VES in low visibility conditions causes visual saliency, as the system can drag too much attention to the visually enhanced elements. With this knowledge, it would not be safe to implement currently existing VES in HUD displays as too much visual saliency is likely to occur. However, it could be interesting to investigate whether VES could be implemented less aggressively leading to less saliency. In addition, the selective enhancement could be adjusted in such a way that it selects to enhance highly important elements such as obstacles on the road instead of road linings. This could turn the enhancing system into a warning system as the saliency will only occur when highly important elements are present, such as obstacles lying on the road. These elements need to be seen quickly by the driver in order to safely adapt to the situation. Therefore, the current VES systems may not be safe to implement in HUDs, however, careful adjustments to the system could lead to saliency solely occurring when needed.

Another component that can cause visual saliency in HUD interfaces is the presence of flashing lights inside the image. Flashing lights seem to be noticed more quickly than stable signals against a background of steady lighting (Crawford, 1962). When the background of the interface is flashing, it makes it very hard for the driver to see the steady signal that is laid on top of the background. When the signal itself is flashing, it makes it even more difficult for the driver to process the signal. Visual distraction is likely to be more severe when symbols are flashing or changing abruptly (Edquist, 2008). Regarding these findings, the use of flashing lights may only be useful for warnings or other highly important elements that need to be seen quickly. However, when using flashing lights in HUDs for warning symbols it needs to be investigated first if the flashing warning symbols are not attracting attention for too long, as this will decrease the driver's time to pay attention to the road. Thus, if it is not necessarily needed, it may be better to leave out the use of flashing symbols in HUDs.

Third, high contrasting HUD symbols can cause visual saliency as well and will degrade performance (Gish & Staplin, 1995). Therefore, it is questionable whether HUDs are safe to operate at night time as this will likely increase the contrast between HUD symbols and the driving scene. The maximum acceptable luminance-contrast ratio of 4:1 is not achievable by some HUDs at low background luminances, because the luminance can not be set low enough (Gish & Staplin, 1995). Whenever these requirements can not be achieved, the use of a HUD display in nighttime could cause visual distraction. Although the contrast ratio can be too big in the night time, in bright sunlit environments the contrast is likely to not reach an acceptable ratio. The minimal luminance-contrast ratio that a HUD should be capable of against an environment in a luminance range of 0 to 8,000 fL is 1.15:1 (Weintraub, 1992). In bright daylight conditions, a minimum luminance-contrast ratio of 1.5:1 is preferred, however, HUDs seem not to meet these requirements which results in a low visibility of the HUD display. When viewing a HUD display against sunlit snow, the luminance of the sunlit snow is roughly 34,000 cd/m_2 (the amount of light that a surface emits). When maintaining the maximum luminance-contrast ratio of 1.5:1 against a background of 34,000 cd/m_2, the luminance of the HUD display should be 17,000 cd/m_2 (fig. 3) (Weintraub, 1992).

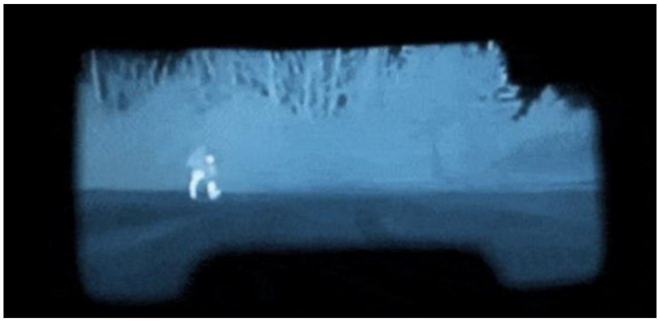
Fig. 3 - Schematic indication of the optimal enhancement-contrast ratio in HUDs. The maximum and minimum lines are estimated for the GM Hughes DataVision HUD (Gish & Staplin, 1995).



The currently available technology is unable to meet these kinds of requirements and even if it would, the light source could possibly melt the HUD system. Gish and Staplin (1995) reported that the combiner on which the HUD image is displayed could be made more reflective in order to upscale contrast. However, when using a tinted more reflective combiner inside the central view, this would result in less transmittance of the combiner against the driver's environment. The lower transmittance seems to be more accepted by drivers when it is located in the peripheral field compared to the central view (Gish & Staplin, 1995). According to these findings, placing a tinted combiner (to display the HUD information on) in the peripheral view can help to maintain a luminance-contrast ratio of 1.5:1 against bright-lit backgrounds. Additionally, the HUD should preferably not contain an enhancement-contrast ratio greater than 4:1.

Although the operation of a HUD in low background luminances may cause too much saliency, using a night vision thermal camera in a HUD display to enhance pedestrians, cyclists or animals in nighttime could increase the driver's range of vision (fig. 4) (Kallhamer, 2006). In bad visibility conditions like dense fog or at nighttime, it can be hard for the driver to see any contrast in the scene. A HUD display could help the driver's observing abilities by displaying a night vision thermal camera view. The use of of a HUD display at night may not be able to achieve a lower enhancement-contrasting ratio than the acceptable 4:1 ratio, however, in these circumstances, it could act as a warning system in which saliency can be useful. When applying this camera view safely it could prevent collisions with vulnerable road users. However, when making use of this thermal camera, the placement of the image information may preferably be in the peripheral view. As seen, VES systems that are projected right in front of the driver's eyes can cause too much visual saliency. Future research is needed to investigate whether HUD enhancement-contrast ratios could be lowered to a maximum of 4:1, in order to safely implement night vision thermal cameras in HUDs when driving at low contrasting conditions.

Fig. 4 - Night vision thermal camera applied in HUD interface HUDWAY.



4 Conclusion and Interface Proposal

In this section, all the findings are discussed shortly and taken together to create a proposal for a HUD interface, which is optimally designed to be observable and prevent visual distraction from visual clutter and saliency. To start off with a short summary of the findings to take into account when designing a HUD interface:

- Using up to four symbols is recommended. A maximum of five or six can be handled if cleverly designed according to Donkor and Burnett (2012).
- Place non-conformal symbology at least 8 degrees outside of the central vision of the driver.
- It is recommended to not use a VES system in a HUD display that is unnecessary visually salient (e.g. highlights every single car on the road, which is not important). VES may only be useful to act as a collision warning system.
- Solely make use of conformal symbology when making use of a safe HUD overlay design inside the central view of the driver.
- It is recommended to not make use of flashing symbols. The use of flashing symbols may only be useful to act as warnings.
- Maintaining a luminance-contrast ratio of 1.5:1 is recommended. In bright-lit environments this can be achieved by making use of a tinted reflective combiner.
- If the HUD display is capable to not exceed the maximum enhancement-contrast ratio of 4:1 in low contrasting environments, the use of a night vision thermal camera can be considered.

These design suggestions will contribute to a human observable and less distracting HUD display. The findings are taken together and implied in a proposed interface, which one can see in the figure (fig. 5). It emphasizes all the above-named recommendations. The interface contains four symbols to keep the image simple and non-distracting: 1) alphanumeric speed symbol; 2) speed limit symbol; 3) navigation direction symbol; 4) alphanumeric distance indication until action. The colours of the symbols are kept as neutral as possible. The display only contains a shade of red to make the speed limit symbol slightly more salient than the other symbols, as this is important information for the driver. In addition, the HUD is placed in the peripheral view of the driver, thereby the non-conformal symbology is not situated inside the central vision of the driver. The decision has been made to not use a VES system here, as the current systems are likely to cause too much saliency. No flashing lights are implemented in the display, however, warnings may be displayed in brighter colours or appear flashing for approximately a couple seconds so that the warning can be shown short but effectively. Lastly, the HUD interface is displayed on a tinted reflective combiner in order to be observable in bright-lit environments.

Fig. 5 - HUD interface proposal. The HUD display (right) and what it looks like from the driver's perspective (left).

5 Discussion

The main question of this thesis entitled how human-technology interaction of HUDs can be optimized by minimizing visual distraction and increasing observability. Different possible solutions have been discussed to make a HUD observable and prevent visual distraction from clutter and saliency. The proposed HUD interface can contribute to a more observable and less visually distracting system than some of the current HUDs. By making the HUD display observable for humans and limiting the amount of distraction, it could be a promising system that emphasizes human usage. Future research could test an interface that looks like the proposed interface to investigate driver performance. When doing this, comparisons should be made between different HUD layouts, whereas the current literature mainly focuses on differences of performance between HUDs and HDDs. It may already be clear that HUDs can outperform HDDs, but to make a HUD optimally safe, comparisons of performance between different interfaces are needed. HUD interfaces containing four symbols could be compared to HUDs that use five to six symbols, in order to investigate whether there exists an optimum number of symbols that is both observable and not leading to visual clutter.

The resulting HUD interface tries to emphasize all the findings of the reviewed literature, however, an addition could be further investigated. As drivers from the experiment by Charissis and Papanastasiou (2010) rated conformal symbology in a VES as helpful, it might be interesting to investigate whether this system could be used to display warnings. VES is likely to cause saliency and although this might not be useful in the symbols of the HUD that do not require direct attention, it might be useful to solely use VES to warn drivers for the highly important elements like lead vehicles that come up close or to warn for obstacles on the road. In addition, the current VES system, that enhances the contours of surrounding vehicles that do not require direct attention, could be adjusted in such a way that the symbols are not visually salient. By using lower enhancement-contrast ratios these symbols might attract less attention and still have a function. However, this needs to be tested carefully and measurements of driver's perceiving only are not enough to test road safety. Experiments involving driving performance (e.g. that involve the measuring of the chance of collisions, eye gaze and behaviour) should be carried out as driving performance can be related to road safety. These ideas must only be implemented when they enhance the abilities of the driver.

In this thesis, the most important topics that relate to visual clutter and saliency are discussed. However, not all topics that relate to visual clutter and saliency are mentioned as the available literature discusses too many factors to include in a thesis of this size. As not every topic is covered, possible adjustments and additions could be made to the proposed interface in order to enhance observability and decrease visual distraction even more. Further research could be done to investigate if enhancement-contrast ratios of HUDs can be lowered to a maximum of 4:1 in low contrasting environments. Whenever this requirement can be met, the use of a night vision thermal cameras can be tested to see if this may have an increasing effect on driving performance. However, if a HUD does not succeed to meet this enhancement-contrast ratio, it may be safer to shut the HUD off in low contrasting environments.

Additionally, this literature review made an attempt to draw a clear line on what design choices to make when creating a HUD interface. This is needed as the available literature sometimes consists of contradictory information and current HUD designs rely mostly on common sense instead of scientific support. To give an example, there is research discussed that supports the use of VES (Charissis & Papanastasiou, 2010) and research that suggests that VES is leading to too much visual salience (Sharfi & Shinar, 2014). This thesis provides a clear recommendation in which circumstances the use of VES may be useful and specifically whenever it is not acceptable. The given recommendations and the HUD interface proposal can contribute to an enhanced human-technology interaction of HUDs. The proposal incorporates the human abilities and characteristics in order to supports human usage. Therefore, this thesis acts as a little step towards the goal to correctly implement HUDs to enhance road safety.

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