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To See or not to See – Innovative Display Technologies as Enablers for Ergonomic Cockpit Concepts
Ergonomic requirements future mobility future functionality

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Introduction

Given the fact that the driving task will remarkably change by the increase of assistance and information systems in the future innovative display technologies play a central role for the ergonomic realization of the driver vehicle interaction. Increasing assistance and even automation of the driving task do not lead to a decrease or disappearance of visual information but instead request new and in some cases revolutionary concepts to close the loop between driver, vehicle and traffic environment. Augmenting information in contact analog head-up-displays for navigation and driver assistance is a very promising approach. Replacement of mirrors via camera monitor systems is a further example. Free programmable cluster instruments in combination with HUD promise to resolve the problem of information density produced by an increasing amount of ADAS and IVIS functionality.

The driving task is by its nature very visual, therefore the integration of additional visual information needs specific care. Relevant requirements are compiled in ISO 15008 and guidelines like ESOP. From an ergonomic point of view the potential offered by innovative display technologies is huge. In many cases the solutions cited above show high potential for an ageing driver population and its visual limitations to ensure a safe and comfortable individual mobility. But for an efficient usage ergonomic rules and guidelines are necessary to avoid driver distraction and ensure readability and intuitive usage of these systems that are remarkable change for drivers that are suited to optical mirrors and static mechanical cluster instruments.

In the following the UR:BAN MMI strategy shows an example how to formulate ergonomic guidelines for the integration of different display technologies. Furthermore the potential of digital human model RAMSIS cognitive for the early development phase of a camera-monitor system to replace the mirror will be shown. Finally the integration of augmenting information in a contact analogue head-up-display will be discussed from an ergonomic point of view.

Free programmable instrument cluster

The instrument cluster (IC) represents one of the first in-vehicle components to transmit all the driving-related information to the driver related to the primary driving task and acquired by advanced driver assistance systems (ADAS) and partially driver information systems (IVIS). Over the last years, more and more components found their way into the car, assisting the driver with visual, acoustic or haptic feedback. Nevertheless, the IC is still the primary human-machine-interface (HMI) in the line of sight of the driver (Blume, 2011). The so called freely programmable instrument cluster (FPIC) has been developed from the classic and pure mechanical IC. It started with smaller displays located between the analogue speedometer and rev counter (Reif, 2010) towards a complete digital display which was first used in series production in 2008 (Burghardt, 2009; Winner et al., 2012). From an ergonomic perspective a free programmable display is not a benefit by itself but clearly raises the question how to use the flexibility for optimized information presentation in relation to the actual context. General goals for the concept are to inform the driver unambiguously with a minimum of visual demand and avoid clutter of information.

Focusing on ADAS in the urban driving context the project UR:BAN (UR:BAN, 2014) developed a modular system to assign the FPIC (and other components) to different terms of presentation timing and action requests of the driver (see Figure 1). Each phase of the system requires a different action from the driver at different times to collision (TTC) (Götze et al., 2014). While the early warning in phase 1 is characterized by the increase of attention in general in order to inform the driver about upcoming driver related scenarios, phase 2 and 3 indicate a specific action where the driver should or has to act in order to prevent an incident. The last two phases will help the driver in terms of an emergency brake and the de-escalation right after bringing him back in the loop.

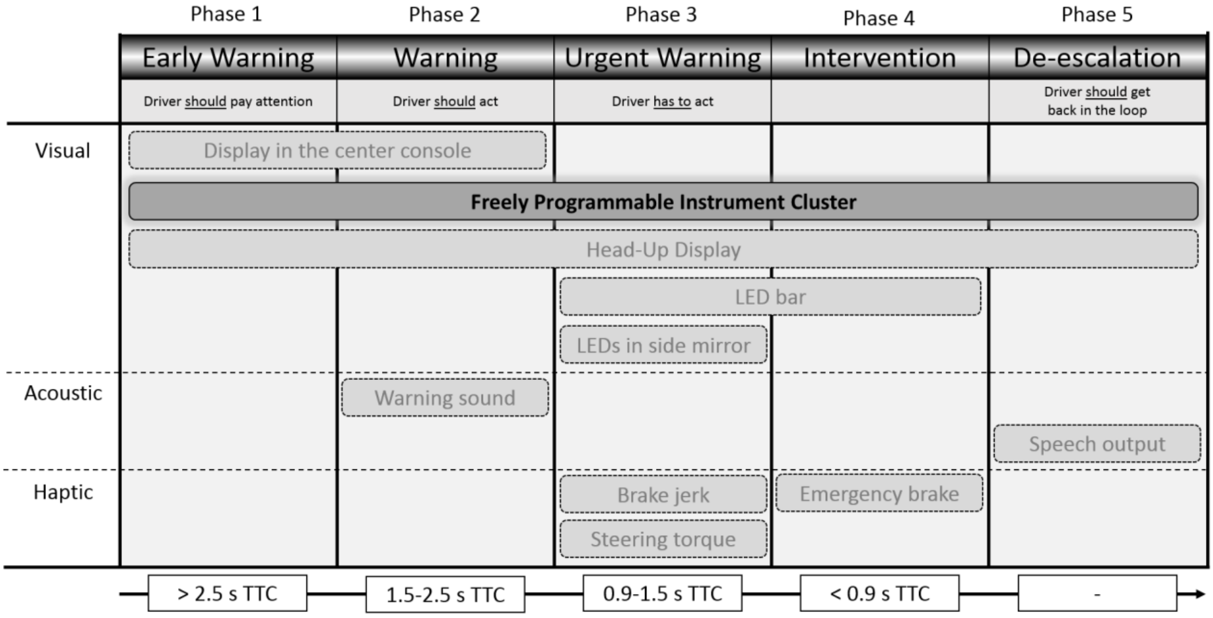

Figure 1: Different terms of presentation timing and the action request for some components of different modalities

But the modular system is not only suitable for warning and emergency scenarios; also information about the operation of vehicle control systems or action directives for CO-2 efficient anticipative driving. In all of those strategies, the FPIC plays a major role as the center component integrated in all kinds of vehicles. Other components as the Head-Up Display (HUD) or an Acceleration Force Feedback Pedal (AFFP) will only be available in more expensive cars, while displays in the center console of the car do not satisfy the requirements of all phases and strategies in the UR:BAN modular system (Petermann-Stock & Rhede, 2013).

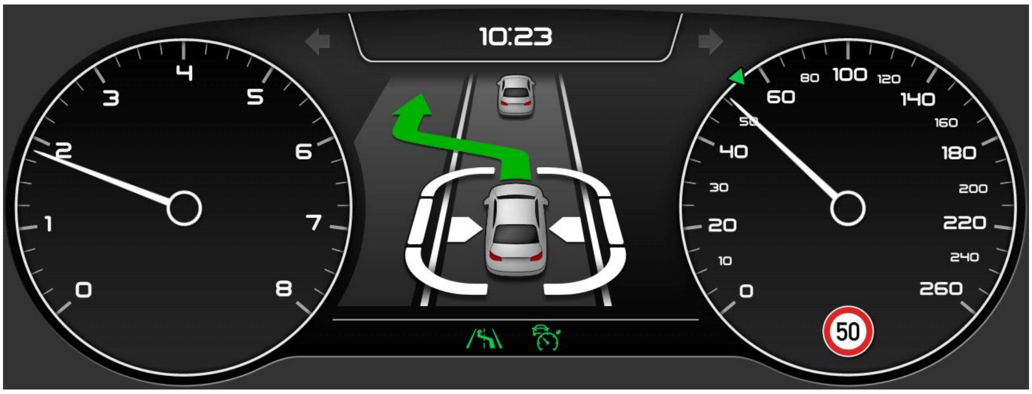

Figure 2: Integration of ADAS and IVIS Information in a free programmable display following the UR:BAN idea

In order to optimally inform the driver in the FPIC without distracting the driver, specific design criteria for warnings and information need to be defined. This is usually done in three steps, starting with defining the warning and information requirements in general for specific scenarios, defining concept specific criteria depending on the overall HMI, and finally the component specific criteria for the FPIC itself. Figure 3 sums up the general requirements for in-vehicle display components. The information given should be able to be quickly learned. This is done by keeping the presented information simple with a concrete presentation of the required reaction of the driver, by showing specific information in the expected location, and by keeping it logical and comprehensible. Furthermore, the information should cause only a low visual workload in addition to the already very demanding driving task. This can be done with generic symbols for different ADAS which require the same action or give the same information (for example two different longitudinal ADAS, like the passive distance control system or the adaptive cruise control [ACC], where both systems present the suitable distance to the preceding vehicle through one generic symbol); this also helps to expand the HMI later with new assistance systems. The driver does not need to know which of the systems provides the given information. Moreover, the shown information should be limited in colors; red should be used for time critical warnings and yellow for early warnings or scenarios that might become critical.

Figure 3: General requirements for in-vehicle display components to inform the driver the best way possible without distracting too much

The concept specific criteria depend on the availability of other display components available in the car and usually include the recommendation to use the FPIC as the center component which gets extended by other displays and modalities. The integrated overall concept will have the advantages of all components while avoiding the disadvantages as much as possible. The term “integrated” refers to the cooperative use of all available components where the single component is not considered individually but in terms of value added to the overall HMI concept.

The FPIC specific criteria can be divided into qualitative and quantitative ones. For qualitative requirements, the driving-related information should be presented in a central position while status information are best shown in the lower part and textual information in the upper part. Content related information should be presented where the main source of this information is normally available, like the speed of the ACC can be placed in the speedometer. Furthermore, longer glance aversion compared to the HUD or shorter ones compared to the display in the center console should be taken into account and also possible fatigue caused by accommodation (Abel et al., 2005). The speedometer design should be kept analogue especially in Europe where studies showed a strong advantage over digital speed designs (Burghardt, 2009; Winner et al., 2012). Additionally, a higher luminance level for elderly should be taken into account (Belotti et al., 2004). Finally, pop-ups should only be used in time critical situations since other important information might be crossfaded. Most of the quantitative requirements can be found in ISO standards. For example, the minimum character height is 4.19 mm, the optimal height 6.98 mm and the spacing between words is the width of the letter "o" (DIN EN ISO 15008, 2009). Symbols should be at least 32 px x 32 px in size and adapted to the used size of the FPIC of 10" – 14" (Winner, 2012). More information about the luminance ratio or the percentage of the usable display area is well researched in previous articles (Burghart, 2009; Belotti et al., 2004).

In summary, it can be said that the FPIC offers the opportunity to flexibly and simply present complex information in a very prominent location. The component can be used in an integrated HMI concept as a primary HMI component expanded with other visual, acoustic or haptic components, depending on the availability in the car. The HMI concept itself should be plain and simple to support the learnability, and the use of concrete information of the required reaction to keep the recoding effort low.

Augmentation in a Contact Analog HUD

In comparison to cluster instruments head-up displays (HUD) enable the presentation of driving-related information via a virtual image in the driver's primary field of vision. This helps the driver to monitor Advanced Driver Assistance Systems (ADAS) and other driving-related information, such as the speedometer, with minimum focal accommodation and eye movement effort, that is, while keeping his eyes on the road. Thereby eyes-off-the-road times are minimized and reaction times to unexpected traffic events are speeded up (Gish & Staplin, 1995; Kiefer, 1998, 2000).

An advancement of the conventional head-up display technology is the contact analog head-up display (cHUD). This technology allows to present information in augmented reality manner, i.e. to expand the view of the real driving environment by virtual information in the head-up display. In contrast to the conventional HUD, information in the cHUD is already correctly superimposed on the real driving environment (see Figure 4) By providing the immediate spatial context, contact analogy in an automotive HUD is supposed to reduce the mental effort necessary to interpret the information and transfer it to the traffic situation. This is supposed to increase situation awareness, safety, and comfort while driving. This is a remarkable advantage to any other information presentation approach. Furthermore, it can help to increase system awareness of ADAS such as ACC.

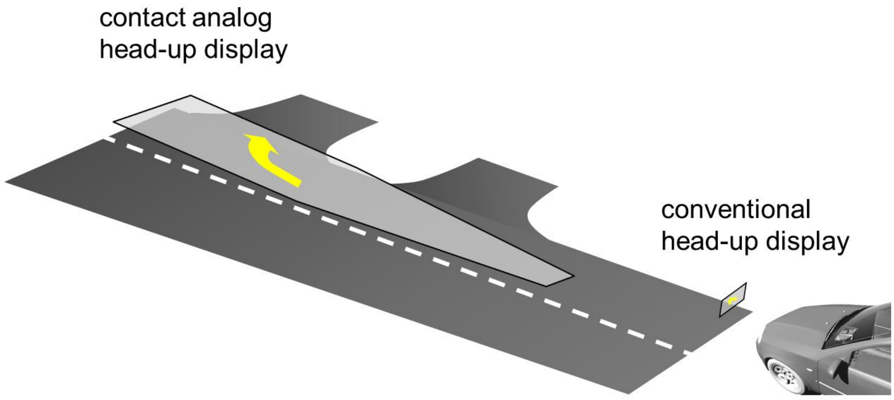

Figure 4: Depiction of the virtual image planes of a contact analog and a conventional head-up display.

Although augmented reality technology is booming and has already reached many areas of application, there are several challenges to series application of a cHUD in an automobile.

One problem is that positional accuracy of the virtual elements in the cHUD and the perceived quality of augmentation are strongly affected by sensor data and vehicle movements. Standard GPS sensors are only accurate up to 3m, street maps and predictive road data – the basis for modern navigation systems – only reach maximum accuracies of 5 – 10 m (without DGPS). In a cHUD, inaccuracies like these may lead to a deviation of the virtual information in the cHUD from its ideal position. Likewise pitch and yaw movements of the car can lead to displacements of the virtual image in horizontal and vertical direction by several meters (Schneid, 2009). These possible deviations or positional inaccuracies must not lead to impairments in driving safety and comfort. In a current study in a static driving simulator (Pfannmüller, Walter, & Bengler, 2014) addressing this problem, was shown that deviations of a navigation arrow of up to 6m have a significantly negative impact on driving behavior (navigation arrows) and usability. Deviations of up to 3m, however, did not lead to such negative effects. The lack of effects on perceived workload and measures of lane keeping quality (SDLP, SRR) suggest that safety might not be as impaired by positional inaccuracies as previously feared. Nevertheless, how these results translate to driving in the real environment and also to other ADAS is subject to ongoing research.

Another challenge to series production are package limitations, which determine the maximum display range of the virtual image. Due to the resulting limitations especially in the horizontal plane, information in the cHUD cannot be displayed in contact analog manner across the whole windshield but will either be cut off or has to renounce contact analogy at some point. This has to be considered when developing concepts for presenting information in the cHUD. How this problem and possible conceptual solutions to it - such as a combination of contact analog and stationary (2D) information - affect the driver is still to be investigated.

Furthermore, the impact of an overlap of the virtual information in the cHUD and real life objects (e.g. other vehicles) negatively affects the perceived quality of augmentation and has an impact on depth perception (Pfannmüller, Walter, Senner, & Bengler, 2014). Importantly, content in the cHUD must not lead to a decrease in the perception of and reaction to critical events in the real traffic environment. Therefore, smart concepts for the presentation of virtual information in the cHUD have to be designed and tested in naturalistic driving studies.

While there are already recommendations for a safe and ergonomic use of conventional automotive HUDs (see for example Milicic, 2009) based on empirical studies (although mainly in the driving simulator), research on cHUDs has been sparse and needs to be extended in order to advance this technology towards series application.

In order to be a fair and viable competitor to the conventional HUD, general optical quality of current cHUD systems have to be improved. This implies a minimization of optical aberration and the definition of minimum requirements for luminance and contrast ratio (right now, specifications for conventional HUDs serve as an orientation). However, some of the technological limitations mentioned above will most probably not be eliminated in the near future and there will certainly never be a “perfect fit”. Therefore, robust, error-tolerant concepts for the presentation and prioritization of information in the cHUD within the technological boundaries are required.

As information in the cHUD is presented in the driver’s safety-critical primary field of vision, it should only be displayed if necessary (situation-adaptive) and desired by the driver. Most manufacturers also agree that only driving-related information should be displayed there. As in a conventional HUD, display clutter and highly salient, obtrusive designs should be avoided, although a comparison of different cHUD display concepts for ACC revealed surprisingly little differences between a minimalistic and a very salient, stimulating display concept concerning workload and standard deviation of the steering wheel (Israel, Seitz, Bubb, & Senner, 2010). All in all, future research should further aim at developing and evaluating guidelines for the safe and ergonomic design of display concepts for the presentation and prioritization of information in a cHUD in the light of the technological and environmental limitations, and the characteristics of the information to be displayed.

Camera Monitor Systems

Compared to the system related information presented by cluster and HUD, the driver also needs to gather additional information about the driving environment. Such the visibility in a vehicle can be defined into direct view, indirect view and the view onto instruments (Remlinger, 2013). The definition of Remlinger is in this case, however, slightly modified. Direct View is thereby defined as the unmirrored vision to the outer field of the car. Indirect View is the mirrored vision to the outer field of the car. The instrumental view is the view to a synthetic display of physical conditions.

Basically, as already discussed each of the views may be replaced or extended by one or more displays. However, the basic requirements are fundamentally different for different applications. The instruments-view is nowadays often shown by displays, having the lowest (safety) requirements.

One possible future application for the replacement of direct vision by camera-monitor systems are remotely operated vehicles (Tang et al.,2014) Other, already present applications are visual augmentation systems such as bird-eye-view. In the following we address the indirect vision in the vehicle:

Displays showing indirect vision are quite common these days. Rearview cameras are well known as assistance for reversing (Fornell, Fagerström, & Gårdlund, 2012). In ISO FDIS 16505 (2014) the basis for a replacement of the required mirrors by CMS is set. In the standard draft the necessary properties of CMS are defined. Reference is given there by the respective known mirrors. Premise is that mirror replacements shall meet at least the same positive characteristics as the current mirrors have. However, some properties of real mirrors simply cannot be achieved by CMS. In these cases other solutions have to be found. For example, one of those properties is found in the latency of the system. Real mirrors don’t have any latency. In this example a limit between the real scene and its representation of 200ms was defined by the ISO working group (ISO FDIS 16505, 2014). In yet unpublished studies with volunteers on the driving simulator and tests in the real vehicle, this latency seems to be safe and unrecognized by the driver.

The most essential requirement of indirect vision for the driver is to get a quick overview of the entire situation. From this basic need, three basic requirements for CMS and its displays are defined:

- Image quality
- Imaging inside the display
- Positioning of the display

The image quality describes physical demands on the CMS. Frame rate, latency, and resolution are some examples for that. In the following we will discuss the necessary resolution. Display resolutions are defined by the number of pixels in general. However, this definition is not decisive for the design of a display in the vehicle. Important is the distance from the eye to the display in combination with the resolution (ISO FDIS 16505, 2014). To acquire the driver's license of the class C (commercial vehicles) in Germany a visual acuity of 80% is required, which corresponds to a resolution of 1,25 arc minutes, or a pixel-size of 1,2mm at a distance of 1m (FeV, 2014). Besides the resolution the magnification factor of a CMS is important. The magnification factor determines the size of an object shown on the display. In ISO FDIS 16505 (2014) factors were defined for each field of view according to those of actual mirror systems.

The Imaging inside the display is for mirror-replacement one of the most important issues. Which areas of view have to be displayed on the screen? In ECE R46 (2009) the fields of view are defined for mirrors in a static position. One basic attribute of mirrors is not being used statically. The field of view can be shifted by a head movement of the driver. As a result, the driver has an expanded field of view. Driver surveys and truck driver observations have shown that these movements are often performed by the driver (Zaindl et al.,2013 & 2014; Bothe et al., 2012)

Figure 5: Expanded field of view by a bending forwards. Comparison of real and simulated behavior

Mirror replacement should therefore be able to represent the area that a person covers nowadays by head and body movements (Bothe et al., 2012). For this issue, a method in RAMSIS in CATIA was developed and validated for heavy duty trucks (Zaindl et al.,2013 & 2014). Main result of these and other studies is that the main movement is done by a bending forward, and the main issue of the driver is to see the back end of the trailer in the main mirror. (Zaindl et al., 2014; Bothe et al., 2012)

Knowing all these information above, the imaging inside the display can be developed. The displays shall show at least the same information in the same quality as nowadays mirrors. If all mirrors would be replaced separately, six displays would have to be placed into a truck's cabin. This does not seam to be the right way. A merge of different field of views in an image seems to be a promising solution. Since the displays should be on a similar positon as nowadays mirrors are, it's favorable to combine the fields of view on each side of the truck (Zaindl et al. 2014 (II)).

Figure 6: Comparison between the current mirror system and the developed CMS prototype on the passenger side of a commercial vehicle

The imaging concept of the CMS-prototype combines the field of view from the current three mirrors into one single display. This results in several advantages for the driver. Since the monitoring is done only in one display, the driver can get a faster and safer overview of the surrounding. Objects can be recognized easier, and truck drivers can be relieved. This type of display is currently being evaluated in studies with volunteers.

Discussion

The three examples discussed above show that different technology approaches can have a remarkable contribution to in vehicle visual information presentation. Being implemented they would follow different visual perspectives and principles to translate system information and outside views to the driver. Also they use different temporal previews to support anticipation as only the FPCI is able to give an abstract projection to a future state, cHUD and camera-monitor systems are limited to the visible reality. Depending on their usage some of the systems and information should be available permanently or show safety critical warnings only temporarily and situation dependent or even should hand it over from one display to the other. Definitely the selection shows candidates that enhance the direct view, the indirect view and the view onto instruments onto the same vehicle and traffic reality.

It is obvious that it will be reasonable to consider homogeneous image quality, imaging and optimized positioning of the display relative to each other to reach an ergonomic driver work place.

If these technologies shall get usable for the driver, requirements of future users and driving task characteristics have to be analyzed more in detail to be able to formulate specifications for each technology but also for solutions that integrate them all together to avoid unreasonable redundancy or confusion.

A main topic will be the visual capabilities of ageing users as many standards and guidelines are still based on non actual demographic data.

A closer look shows that recommendations for highly innovative display concepts need to be refined and updated. Current standards focus on the readability of fonts and symbols. Future concepts will include more photorealistic and augmenting visualizations that might be highly related to objects in the traffic scenery to support cooperative driving scenarios in highly automated vehicles (Zimmermann, 2013)

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