"A Careful Driver is One Who Looks in Both Directions When He Passes a Red Light" – Increased Demands in Urban Traffic

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Abstract. This paper summarizes the requirements of an HMI concept for urban areas including the vehicle components: Head-Up Display, the Instrument Cluster, and the Acceleration Force Feedback Pedal. The research addresses all qualitative and quantitative requirements of the aforementioned HMI components as well as urban areas and scenarios itself and warnings in general. The results contain almost 150 confirmed requirements by different sources and lay the foundation for future experiments in this field.

Keywords: HMI, HCI, urban, driving, cockpit, hud, fpk, instrument, cluster, force, feedback, pedal, affp, warnings, adas, assistance.

1 Introduction

The witty quote in the title of this paper comes from the late Ralph Marterie and resonates familiarly with urban driving. Although the driver is obviously very careful passing the crossroads, he at the same time ignores or overlooks the red light and proceeds to cross the road. The mental and visual workload seems to be too high and the human-machine-interface (HMI) did not support the driver well enough to avoid a potentially dangerous situation. This can happen because of several reasons, especially in urban areas, like higher complexity of the situation (Schröder, 2012), multiple road users or obstructions of road signs or parked cars (Schartner, 2013). Nevertheless, driving has become much safer the last years (Reif, 2010). This increase of safety is partly due to the increase of security systems and legal provisions (Hütter, 2013). However, accidents still do occur. According to Hütter (2013) in 2011, left/right turns, U-turns, entrances and exits, right of way, speed violations and short distances, were associated with the majority of auto accidents with personal injuries. Most of these complex situations and use cases can be assisted by advanced driving assistance systems (ADAS). Additionally, it is necessary to avoid overloading the driver with unhelpful visual, acoustic or haptic information. For this reason, the information

S. Yamamoto (Ed.): HIMI 2014, Part II, LNCS 8522, pp. 229–240, 2014.

presented in the HMI needs to be limited and presented carefully in order to not further increase the already demanding scenario of urban driving (Gevatter, 2006). Existing HMI concepts are characterized in particular by one-off solutions that would overload the driver considering the growing variety of functions with competing and uncoordinated information (Lange, 2008).

In order to keep the workload in urban driving low, we propose a generic and integrative HMI concept with warnings and information presented on specific components in the car; namely, the Head-Up Display (HUD), the instrument cluster (IC), and the Accelerator Force Feedback Pedal (AFFP). These components are able to give a detailed visual and haptic feedback to the driver without causing too many gazes away from the road. The HUD is especially suitable for warnings (Reif, 2010) while the IC can present detailed information without distracting the driver. Additionally, the AFFP presents information haptically (Lange et al., 2010), with the advantage that such signals are processed faster relative to visual feedback (Merat et al., 2008) and do not interfere with other information channels (Wickens, 2002).

The first step to a new and improved HMI concept for urban areas is to first review the previous literature on the three HMI components mentioned, evaluate how to apply these in urban traffic, and to understand the specific characteristics of urban traffic itself (Popiv et al., 2010).

The development of this new generic and integrative HMI concept is part of the collaborative research project UR:BAN (Urbaner Raum: Benutzergerechte Assistenzsysteme und Netzmanagement - Urban Space: User oriented assistance systems and network management) which started in 2012 (UR:BAN, 2013). Thirty partners including automobile and electronics manufacturers, suppliers, communication technology and software companies, as well as research institutes from different cities, have joined in this cooperative project to develop advanced driver assistance and traffic management systems for cities. The focus is on the human element in all aspects of mobility and traffic. The research objectives will be pursued in three main thematic target areas: Cognitive Assistance, Networked Traffic System, and Human Factors in Traffic.

2 Qualitative and Quantitative Requirements

2.1 Urban Areas and Scenarios

In 2010 about 68% of all accidents with personal injury occurred in urban areas. Those accidents resulted from several reasons wherefore a holistic approach of the driver, vehicle, and environment seems to be reasonable (Ehmanns et al., 2003). The urban area is characterized by high density traffic with different kinds of road users (ex. bicycles, motorcycles, trains, pedestrians, and cars). Additionally, the scenarios are more complex because of the shorter time window, increased decision making, and the fast sequence of road signs and other notifications (see Fig. 1). Consequentially, the probability of warnings or information by the ADAS is much higher. Table 1 shows the research results found for urban areas and scenarios.

Table 1. Relevant urban area and scenario considerations according to different literature sources. The table describes key concepts that need to be considered when developing a novel HMI concept.

HMI concept requirements and or considerations	**Source**
Complexity of the traffic situation and their elements	(Schröder, 2012)
High vigilance performance at intersections	(Schröder, 2012)
Demand of information acquisition and vehicle operation while changing direction	(Schröder, 2012)
Distinction of urban intersections (traffic light vs. Driveway)	(Schröder, 2012)
No permanent warnings or intervention in self-controlled situations	(Reif, 2010)
Compliance of difficulties for the elderly with the required fast responses in complex and novel situations	(Winner, 2012)
Driving experience, driving style and driver type	(Winner, 2012)
Intuitive comprehensibility of the information	(EN ISO 15005, 2002)
High priority information with appropriate representation	(EN ISO 15005, 2002)
High traffic density in urban areas	(Schartner, 2013)
Diversity of road users	(Schartner, 2013)
High frequency of traffic signs in urban areas	(Schartner, 2013)
High frequency of necessary maneuvers in urban areas	(Schartner, 2013)
Faster decision making need in urban areas	(Schartner, 2013)

2.2 Warnings in General

Warnings can be categorized in terms of presentation timing and content. The "warning dilemma" describes the reliability of a presented warning dependent on the time to collision (TTC). While reliability increases with a shorter TTC left, the effectiveness increases when the driver is given more time to react. Moreover, if the system produces too many false warnings, it might be rated as less accepted and users might even turn it off (Winner et al., 2012). Usually, the information or warning presentation time can be categorized as four points of time: urgent warnings, warnings, early warnings or information, and continuous information (Petermann-Stock & Rhede, 2013). Tab. 2 shows the four points in time when the information or warnings are presented in the HMI concept.

Table 2. Categorization of the point in time when information or warnings are presented

Category	Presentation time
Urgent warning	0.9s – 1.5s TTC
Warning	1.5s – 2.5s TTC
Early warning / Information	>2.5s TTC
Continuous information	-

The content of information can be separated into the categories: action directives/request, situational information, attention control, conditional information, and detailed information. A distinction is made between the range and the complexity of the shown information. As can be seen in Table 3, all categories are aimed at triggering a different driver reactions.

Table 3. Categorization of the content of information given with a warning or information

Category	Description
Action directives/request	Concrete presentation of the required reaction e.g. demand to brake, navigation instructions
Situational information	Specific warning with indication of the type or location e.g. lane change warning
Attention control	General increase of attention or non-specific reference to risky situations e.g. warning tone
Conditional information	Representation of the vehicle state e.g. display of availability or indication
Detailed information	Numerical values or text content e.g. speedometer

Action directives place a high demand on presentation capability, as the action for the driver must be clearly described. This, however, depends on how the driver perceives and consequentially understands this information. In contrast, the situational information leaves the decision of how to appropriately respond to a given situation, up to the driver. It offers him more support than warnings for attention control, because the nature of the critical situation and the location of a potential threat are shown. The presentation of conditional information is important because of the existing technical limitations of current ADAS, as the driver must be referred to the lack of functional readiness of such a system.

In addition to the different presentation times in Table 2, the following three quantitative requirements were found in the literature for warnings in general.

Table 4. Quantitative requirements found for warnings in general

Quantitative warning requirements	**Source**
Area around the line of sight for peripheral information (most precise discovery for peripheral information in this area): 25° vertical / 35° horizontal	(Liu, 2003)
Time interval of two warnings: ≥ 3 seconds	(Thoma, 2010)
Point in time for most effective information of the driver (time to last possible warning): ≥ 1s / optimal 2-3s	(Naujoks, Grattenthaler & Neukum, 2012)

While only a few quantitative requirements were found for warnings, Table 5 shows the qualitative requirements.

Table 5. Qualitative requirements found for warnings signals and information presented

Qualitative warning and information requirements	Source
Linking the position where the warning is shown with the content of information	(Schartner, 2013)
Consideration of the "warning dilemma" and appropriate implementation of the warning	(Winner, 2012)
Avoidance of false reports	(Winner, 2012)
Display the warning near the center field of view for slight deflection and rapid perception	(Commission of the European Communities, 2008)
Avoid the exclusion of the driver from the "loop" for driving task	(Ehmanns, Zahn, Spannheimer & …)
Binding of most of the attention to the driving task	(EN ISO 15005, 2002)
Application of the laws of ergonomic design	(Bengler, 2012)
Chronological and content-based coordination of each successive warning	(Reif, 2010)
Warning includes one of the following: directives for action, situational information, attention control, conditional information or detailed information	(Reif, 2010) (Naujoks, Grattenthaler & Neukum, 2012) (Winner, 2012)
Predictability of situation danger by warning	(Thoma, 2010)
Driver information as late as possible and as early as necessary	(Naujoks, Grattenthaler & Neukum, 2012)
Avoidance of warning tones when presenting driver information	(Naujoks, Grattenthaler & Neukum, 2012)
No detailed information in the peripheral field of view	(Liu, 2003) (Petermann-Stock & Rhede, 2013)
Avoidance of information in critical situations (except warnings)	(Muigg, Meurle & Rigoll, 2008)
Avoid the driver's exposure by warnings	(Winner, 2012)
Conformity with user expectations	(VDI/VDE 3850-3, 2004)
Easy and fast learnability (Place, Design, and link to concrete actions)	(Petermann-Stock & Rhede, 2013)
Clearly located, correlate with need for action, and same quality at the same position	(Petermann-Stock & Rhede, 2013)
Low visual workload – discrete levels in warning situations with a reduced color range (yellow, red)	(Petermann-Stock & Rhede, 2013)
High consistency (clear cascades of strategy, avoidance of multiple assignments of the HMI components, avoid redundancies)	(Petermann-Stock & Rhede, 2013)
Tend to use haptic signals later and visual signals ealier	(Petermann-Stock & Rhede, 2013)
Avoid cognitive capture	(Burghardt, 2009)

Table 5. (*continued*)

Information presented on different HMI components regarding the same issue needs to be associated in some way	(Burghardt, 2009)
Faster visual fixation of dynamic objects	(Burghardt, 2009)
Consistent use of the colors red, yellow and green according to their meaning	(ISO 2575, 2010)
Use existing and standardized graphics designing new symbols	(ISO 2575, 2010)
Shape of symbols according to their importance and meaning	(VDI/VDE 3850-1, 2000)
Representation of visual information as long as necessary	(EN ISO 15005, 2002)
No coverage of warning messages	(VDI/VDE 3850-1, 2000)
Represent the right information at the right time	(Commission of the European Communities, 2008)

HMI Components. Every component of the HMI concept has specific advantages and disadvantages (Ablassmeier et al., 2007) regarding presenting warnings or information in urban areas. The aim of the current article is to provide the ground work to develop a generic HMI concept that incorporates as many advantages as possible and eliminates, when feasible, as many disadvantages as possible. For this reason, the characteristics and requirements of those components have been specified from earlier studies and publications.

2.3 Head-Up Display (HUD)

The Head-Up Display is a relatively new visual HMI component which projects information in the driver's windshield. In this case, a virtual image is produced by mirror systems with a perceived optical distance of about two meters in front of the vehicle hood. Originally HUDs were developed as monochrome, but newer versions are developed with polychromatic capability (Schneid, 2008).

The biggest advantage of a HUD is that relevant information is given central in the visual field, meaning that distraction and diversion of the gaze are reduced to a minimum. This of course involves the danger that too much and unimportant information will be shown which unnecessarily increases workload. Table 6 summarizes the qualitative requirements and Table 7 the quantitative requirements found for the HMI component HUD.

Table 6. Qualitative requirements for the HMI component Head-Up Display

Qualitative requirements of the HUD	Source
Usable for Pop-ups, icons, and control information	(Petermann-Stock & Rhede, 2013)
Level of detail: HUD < IC	(Petermann-Stock & Rhede, 2013)
No overlap of the driving scene	(Winner et al., 2012)
The HUD is not a substitute for the IC (additionally)	(Reif, 2010)
Avoid the overload with content	(Reif, 2010)
Restricted to time-critical, situational, and dynamic information	(Weber, 2005)
Presentation of safety relevant information	(Winner et al., 2012)
Presentation of driving related content & prioritized content	(Abel et al., 2005)
Continuous adaption of the brightness to the background	(Abel et al., 2005)
Targeted use of the HUD for binding of attention to the road	(Abel et al., 2005)
Use the advantage of faster RT of the HUD compared to the IC	(Raubitschek, 2008) (Liu, 2003)
For presentation, consider the “shrink effect”, “cognitive capture”, “novelty effect”, and the “information clutter”	(Liu & Wen, 2004)
Consider the “perceptual tunneling effect”	(Raubitschek, 2008)
Use the advantage of a more constant maintaining of the speed	(Liu & Wen, 2004)
Use the advantage of a stricter observance of road signs	(Liu & Wen, 2004)
Use the better awareness of speed with a HUD	(Liu & Wen, 2004)
Clearly structured representation (consistent allocation)	(Weber, 2005)
Lower complexity of information and design	(EN ISO 15005, 2002)
No representation of important information at the corners of the displayed area	(Weber, 2005)
No static indicator lamps in the HUD	(Weber, 2005)
Avoid warnings right before take-over requests	(Weber, 2005)
Avoid using the colors red and blue (at night time)	(Raubitschek, 2008)
Use the “fading effect” for changing information	(Milicic, 2010)
Avoid animations (grabbing attention) for information, it should be reserved for warnings	(Raubitschek, 2008)
Useful use of scaling for prioritization of messages	(Milicic, 2010)
Useful use of dimming for selective attention control	(Milicic, 2010)
Avoid overlap of content	(Milicic, 2010)
Specific fade-out of irrelevant content	(Milicic, 2010)
The amount of textual content should be limited to a minimum	(Milicic, 2010)
Avoid straight lines due to distortion in the displayed area	(Milicic, 2010)

Table 7. Quantitative requirements for the HMI component Head-Up Display

Quantitative requirements of the HUD	Source
Minimum character height (at a distance of 3 m): 10.47 mm (= 12”)	(DIN EN ISO 15008, 2009)
Optimal character height (at a distance of 3 m): 17.45 mm (= 20”)	(DIN EN ISO 15008, 2009)
Display duration of road signs shown: ≥ 5 seconds	(Liu, 2003)
Maximum time of glances of the road to the HUD: < 2 s	(Liu & Wen, 2004)
Structuring the viewing areas according to the line of sight: 2°	(Weber, 2005)
Maximum number of colors: 4	(Raubitschek, 2008)
Luminance of the HUD: ≥ 17’000 cd/m²	(Raubitschek, 2008)

2.4 Instrument Cluster (IC)

The traditional version of the instrument cluster shows warning and indicator lights with fixed symbols or small graphics for predetermined information. In addition, in a physical display, the speed and RPM are shown. A more variable representation is provided with graphic modules in the middle of the IC, which are able to display dynamic and changeable graphics and text content in addition to the control lights and analog displays (Winner et al., 2012).

The most versatile concept that is now used mainly in premium vehicles is the freely programmable instrument cluster (FPIC). With this type of cluster, all information is combined on to a large graphics screen, which enables the virtual simulation of an analog speedometer and RPM, and additionally detailed graphical content such as navigation maps, night vision systems, or other ADAS (Eckstein et al., 2008).

Tables 8 and 9 summarize the qualitative and quantitative requirements found in the literature for the HMI component instrument cluster.

Table 8. Qualitative requirements for the HMI component instrument cluster

Qualitative requirements for the instrument cluster	Source
Suitability for driving relevant information, early warnings, and warnings in general	(Petermann-Stock & Rhede, 2013)
Link warnings with audible alerts and suitable colors	(Petermann-Stock & Rhede, 2013)
Suitable communication of detailed information in a generic way	(Petermann-Stock & Rhede, 2013)
Intuitive design of the content	(Burghardt, 2009)
Use the IC for monitoring / dynamic information	(Reif, 2010)
Taking longer glance aversion into account	(Abel et al., 2005)
Taking possible fatigue caused by accommodation into account	(Abel et al., 2005)
Presentation of driving related content & prioritized content	(Winner, 2012)
Higher RT with the use of colors	(Winner, 2012)

Table 8. (*continued*)

Display the same type of information in the same area of the display	(EN ISO 15005, 2002)
Taking the lack of a missing local context into account	(Burghardt, 2009)
Use the advantage of analog displays with round panels	(Burghardt, 2009)
Taking higher distraction of digital displays compared to analog displays into account	(Burghardt, 2009)
Display IC content in coordination with the HUD content	(Burghardt, 2009)
Restrict the amount of information displayed to an optimum	(Belotti et al., 2004)
Smaller font size needs a better contrast to be read	(Belotti et al., 2004)
Taking a higher luminance level for elderly into account	(Belotti et al., 2004)
Choose colors according to day or night time	(Götze et al., 2013)
Strategic use of “color fading”	(Belotti et al., 2004)
Differentiation of information and warning content	(Belotti et al., 2004)
Positioning of the content according to priority / frequency	(Belotti et al., 2004)
Limited and fixed number of familiar symbols	(Belotti et al., 2004)
Taking the size of the IC into account	(Belotti et al., 2004)

Table 9. Quantitative requirements for the HMI component instrument cluster

Quantitative requirements of the instrument cluster	Source
Minimum character height (at a distance of 1.2 m): 4.19 mm (= 12”)	(DIN EN ISO 15008, 2009)
Optimal character height (at a distance of 1.2 m): 6.98 mm (=20”)	(DIN EN ISO 15008, 2009)
Compliance of the process of accommodation: 0.3 – 0.5 s	(Reif, 2010)
Representation adapted to the used size of the FPIC: 10” – 14”	(Winner, 2012)
Consideration of the best visual acuity: radius 9 cm	(Burghardt, 2009)
Percentage of the usable display area: 1/3	(Burghardt, 2009)
Luminance contrast between symbols and background: day time: $\geq$ 3:1, night time: $\geq$ 5:1, sunshine: $\geq$ 2:1	(DIN EN ISO 15008, 2009)
Luminance ratio between the display and environment: $\leq$ 10:1	(Belotti et al., 2004)
Minimum spacing between words: width of the letter “o”	(DIN EN ISO 15008, 2009)
Minimum pixel matrix for symbols: 32 px × 32 px	(DIN EN ISO 15008, 2009)

2.5 Acceleration Force Feedback Pedal (AFFP)

The acceleration force feedback pedal is characterized by two functions additionally to the already known feature to accelerate the vehicle in longitudinal direction. On the one hand, it is possible to continuously transmit information like the maximum allowed speed (Lange et al., 2008) and, on the other hand, the driver can get situational warnings like upcoming collisions (Thierfelder, 2007).

The AFFP enables the possibility to add the haptic channel to a new, innovative, and integrative HMI concept with advantages for directives for action in particular. Other benefits are that the driver's visual attention is kept on the road scene and the action indicated by the component is executed with the component itself (Zell et al., 2010).

Tables 10 and 11 summarize the qualitative and quantitative requirements found.

Table 10. Qualitative requirements for the HMI component acceleration force feedback pedal

Qualitative requirements of the AFFP	Source
Avoid vibration of the AFFP for transmit information	-
Use "double ticking" to implement a gear switching point	(Lange et al., 2010)
Use the haptic channel for directives for action	(Lange et al., 2008)
Use adjustable action point to indicate "maintain speed"	(Lange et al., 2008)
Use action point to support distance control to vehicle ahead	(Lange et al., 2008)
Driver can overrule the action point at any time	(Lange et al., 2008)
Some information do not require additional visual notifications (e.g. maintaining the right speed)	(Lange et al., 2008)
Use the potential of transmitting information without gaze movement	(Lange et al., 2008)
Increased sense of security when using visual and haptic elements	(Lange et al., 2008)
Discreet information for the driver (driver not exposed)	(Zell et al., 2010)

Table 11. Quantitative requirements for the HMI component acceleration force feedback pedal

Quantitative requirements of the AFFP
Maximum number of signals: 2 (counter-pressure, action point)
Maximum number of escalating signals: 1

3 Conclusion

The aims of this study were to collect qualitative and quantitative requirements for a generic HMI concept, and to evaluate the urban settings itself, warnings in general, the Head-Up Display, the instrument cluster, and the Acceleration Force Feedback Pedal. The results contain almost 150 confirmed requirements by different sources and lay the foundation for future experiments in this field. The next step will be to build a first version of the generic and integrative HMI concept and evaluate it in the simulator.

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