A real-world driving experiment to collect expert knowledge for the design of AR HUD navigation that covers less

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ABSTRACT

Augmented reality head-up displays (AR HUD) can be seen as a promising advancement of conventional head-up displays in vehicles. Information can be displayed in a contact analogue way in the real world by projecting it onto the vehicle's windshield. Two major challenges for concept developers are to reduce masking caused by *augmented reality* (AR) content and to create concepts that work with the limited *field of view* (FOV). To examine these two challenges, we designed two contact analogue navigation concepts. We compared them to each other in a field study with a prototype car that took place in a residential area with real traffic. The participants were experts in interaction design, AR, HUDs, design, and sales. The experiment showed that the application of *Gestalt Principles* for AR HUD concept design to reduce masking can be a promising approach. Additionally, suggestions for further improvement of contact analogue navigation concepts were collected.

CCS CONCEPTS

H.5.1. Information interfaces and presentation: Multimedia Information Systems

KEYWORDS

Augmented reality, head-up displays, field study, contact analogue, navigation, masking

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1 Introduction

Traffic gets more and more complex and thus, the requirements on drivers rise [6]. Furthermore, today's drivers want to perform multiple activities that are not part of the primary driving task including the operation of in-vehicle infotainment and entertainment systems as well as comfort functions [18]. Therefore, modern cars are equipped with a large number of driving assistance systems (DAS) to give support by relieving the driver in challenging traffic situations [3]. One example for current DAS technologies are conventional head-up displays (HUD) which are already available in many of today's vehicles. This technology makes it possible to display driving-related information, such as navigation cues or the current speed in the driver's primary *field of view* (FOV) through a virtual image that is mirrored in the windshield. Hence, the driver is able to observe the road while accessing driving-related information at the same time. Also, the adaption, accommodation, and eye movement effort of the driver's eyes are reduced to a minimum. Furthermore, reaction times to unexpected traffic events as well as eyes-off-the-road times decrease [18, 29]. The next step in the development process is the integration of *augmented reality* (AR) [2] in HUDs. This makes it possible to combine virtual and real information in the driver's primary FOV via the projection of visual content onto the windshield [28] (see Figure 1). The virtual content is presented to the driver in a contact analogue way which means that the information is directly connected to the real environment [28]. This technology is called *augmented reality head-up display* (AR HUD) and was realized in a car for the first time by Bubb [5]. The AR HUD is supposed to support drivers through a more intuitive way of displaying driving assistance information [4].

Figure 1. Static and contact analogue information in a HUD [9]

Until an AR HUD can be realized in a production vehicle, there are still challenges to master. One of those is the correct superimposition of virtual information onto the real environment which can be problematic due to an inaccurate road map or sensor data. Further reasons for displacement of the AR cues can be the driver's head posture and sitting position as well as pitch and yaw movements of the vehicle. Another challenge is that AR information can only be displayed in a small area of the windshield due to technical limitations. Those limitations will remain in the foreseeable future. Therefore, it is necessary to design for situations, such as curves, where virtual information is cut off. Furthermore, non-contact analogue fall-back solutions are required [29]. Another problem is that superimposing virtual information onto the real traffic environment can lead to driver distraction, annoyance or masking of other road users, such as pedestrians or bicyclists [28]. Therefore, a further challenge in concept development for AR HUD is the reduction of masking while still providing the same level of information.

In this field study two contact analogue navigation concepts for AR HUD are compared with respect to their suitability for the use case *navigation* and their degree of masking the real traffic environment. The goal is to examine whether the integration of *Gestalt Principles* can lead to the reduction of masking effects with a consistent interpretability of the navigation cues at the same time. Furthermore, we want to collect expert knowledge to provide guidelines for navigation concept design for AR HUD. This experiment is one of the first ever that uses a prototype car with a complete AR HUD environment that includes real sensor and road map data and would even provide a free navigation. The detailed description of the setup is given in paragraph *EXPERIMENT*.

2 Previous Work

There are general guidelines for the presentation of visual information in vehicles [8, 12, 13, 30] and also guidelines for HMI design [10, 11]. Studies addressing the design of AR HUD concepts have been conducted as well [22, 28, 31]. In the following, we discuss these topics with focus on the design of contact analogue navigation concepts and the effects of masking.

2.1 Research on Navigation in AR HUDs

Schneid [31] realized a navigation concept in a prototype vehicle that had the shape of a green arrow which points into the direction of the upcoming turn-off point. The virtual arrow is placed at the manoeuvre point and behaves like an arrow painted on the road. This concept was evaluated in a field study in which the idea of a contact analogue navigation hint was rated as positive by the majority of the participants. Among other things, the participants suggested to use a different colour with a higher contrast to the real environment. Furthermore, the usage of a different navigation concept with the shape of a tube was suggested.

Another study addressing navigation for an AR HUD was conducted by Israel [22] who compared three different concepts: A tube that shows the trajectory the driver has to follow, an arrow that is displayed at the manoeuvre point, and a so-called *virtual cable* [17] that resembles a tram power line. The participants had to rate the concepts according to distraction, accuracy, and suitability as a navigation instruction. After watching a video of each concept, the participants rated the tube as the most accurate concept, whereas the arrow was assessed as the less distracting one.

Pfannmüller [28] gives design recommendations for AR HUD in general as well as for contact analogue navigation concepts based on different studies in the driving simulator, in a special AR HUD mock-up, and in the field. A design recommendation for AR HUD in general is that one should avoid covering/masking real objects with AR content or at least reduce this to a minimum. One can minimize masking by e.g. just displaying the outlines of an AR content or by simply switching to a non-contact analogue, two-dimensional visualization. Additionally, the integration of shades in concepts for AR HUD to support the distance perception is not recommended as it affects the visibility of elements in longer distances [28]. Furthermore, the AR content should not be cut off which can easily happen as the FOV of an AR HUD is rather small. In addition, one should be careful not to make the AR content too large or too dominant and also to avoid displaying too much information at the same time as it might overextend or disturb the driver. Pfannmüller [28] points out that only content that is relevant for the primary driving task should be shown in the AR HUD and at the same time, this information should be shown only in traffic situations in which it is really needed. Also, animation should be used carefully and sparely due to its salience which could be used to guide the driver's attention to help him or her to e.g. recognize and react to obstacles on the road like other road users. Therefore, it is required that the displayed animation is understandable or intuitive.

The design recommendations for the use case *navigation* in an AR HUD, given by Pfannmüller [28], contain the recommendation to include a two-dimensional preview of the upcoming manoeuvre. This could help especially when the positioning of the displayed AR content is inaccurate or when viewing conditions are poor. Another advice is to show the driver where to go with the help of a so-called *fishbone* which represents a boomerang-shaped navigation concept that should be preferred to an arrow or a conventional trajectory. While it is also recognized as a trajectory because of the effects of *Gestalt Principles*, the fishbone concept reduces the masking of objects in the real world.

2.2 Masking Effects in AR HUDs

Displaying visual content in the driver's primary FOV is associated with risks. One of them is masking other road users or traffic events [15]. This danger exists in the HUD especially in case of a high amount of displayed virtual elements or a high information density [32, 33]. Due to a corresponding salience, this can lead to an unwanted directing of attention towards the visual content which can result in a non-observance of the real environment [1]. Furthermore, a violation of the monocular depth cue *occultation* which means that virtual information is projected in front of a real object but should be behind it, can lead to confusion and ambiguity [14].

In a field study conducted by Schneid [31] participants criticized the collision of contact analogue navigation cues and real-world objects. Schneid [31] mentioned that the increase of the opacity of the shown AR content could be a solution.

In a study conducted in a stationary prototype car, Pfannmüller [28] investigated whether the overlapping of AR content and a vehicle ahead has an influence on depth perception in case of AR HUDs with standing and lying virtual image plane. The results showed that a collision of virtual image and real object caused an underestimation of the distance of the virtual image in both cases. The study also showed that in case of the system with the lying plane participants had a higher workload when the AR content was colliding with a real object. According to Pfannmüller [28], the reason for this could be the contradictory visual information that has a negative impact on the contact analogue effect. This study showed that masking caused by AR content should be avoided and two solutions were suggested: The visual content could be adapted in case of a detected collision, by e.g. showing outlines only [23]. Another possibility would be to show 2D content instead.

In a simulation study evaluating AR HUD navigation cues, Pfannmüller [28] found that an arrow looking similar to a fishbone was rated higher in terms of clarity, intuitiveness, and the required amount of concentration compared to a solid tube. According to Pfannmüller [28], the reason for that could be that masking caused by the fishbone concept is less and due to that, potentially relevant objects are covered less.

2.3 Summary

The number of research papers that touch upon the investigation on the design of navigation concepts for an AR HUD is rather small. Also, there is not much research done on masking caused by an AR HUD that was conducted in the field. Furthermore, most of those studies have been conducted in a driving simulator with the AR content directly integrated in the virtual driving scene. Hence, no real hardware and sensor data was used and no influences of real environmental conditions were considered either. Thus, we expand the body of research dealing with navigation concepts for AR HUD and the problem of masking the real driving environment. This will be done by conducting a field study to investigate those topics.

3. Navigation Concept Design

Based on guidelines from research (especially the design recommendations from Pfannmüller [28]) and focus groups with experts in the field of AR HUD concept design, two contact analogue navigation concepts for AR HUD have been created. The images in the following paragraphs showing the navigation concept designs, were created using Blender (version 2.78).

3.1 Solid Fishbone Concept

The first concept, the *solid fishbone concept*, consists of three basic elements that we call *entry marker*, *middle marker*, and *exit marker*. All of those three components do have the shape of a fishbone as recommended by e.g. Pfannmüller [28] and Israel [22], to achieve a smoother cut when leaving the FOV as well as less masking of relevant real-world objects. For both concepts a light blue colour was chosen: RGB (102, 153, 230) with a transparency of 0. When the driver approaches a manoeuvre point, the *entry marker* fades in first. The *entry marker* consists of a curved fishbone that lies on the street, connected to the real environment in a contact analogue way, and shows the upcoming turn-off direction (see Figure 2). The fade in and out time is .5 *seconds* for all elements of the *solid fishbone concept*.

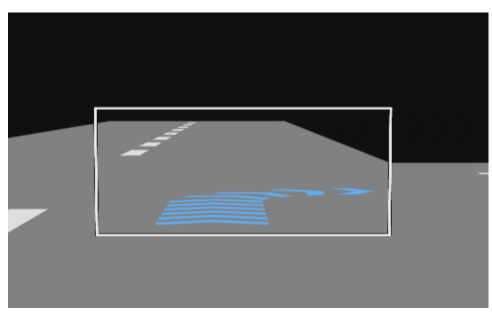

Figure 2. Entry marker of the solid fishbone concept

The *entry marker* fades out as soon as it would be cut off by the FOV of the AR HUD. Next, the so-called *middle marker* fades in which is represented by a wall that is a fishbone standing on the edge and is placed at the centre lane of the road in which the upcoming manoeuvre points into (see Figure 3). The *middle marker* is longer than the FOV and is also shown during turning off.

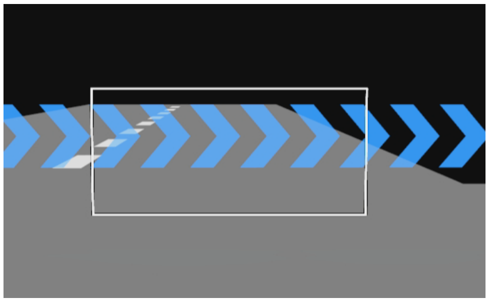

Figure 3. Middle marker of the solid fishbone concept

Immediately after turning, the third and final concept element, the *exit marker*, is shown to the driver by fading in. This component shows again the next turn-off direction in case there is another manoeuvre following soon. Otherwise the *exit marker* just points straight as shown in Figure 4:

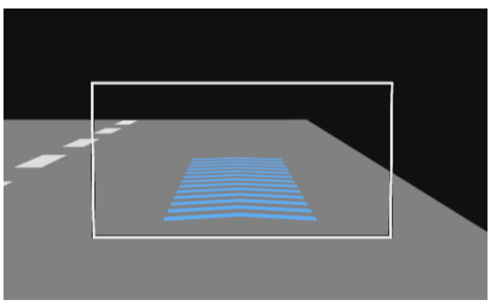

Figure 4. Exit marker of the solid fishbone concept

3.2 Dotted Fishbone Concept

The components and their behaviour are the same for both of the navigation concepts with the only difference that the *dotted fishbone concept* has a dotted fishbone as core element (see Figure 6). The idea is that the driver still recognizes the fishbone shape with the help of *Gestalt Principles*, especially *Principle of Proximity* and *Principle of Good Continuation* which are illustrated in Figure 5:

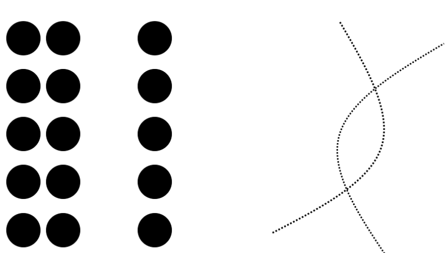

Figure 5. Law of proximity and law of good continuation

At the same time, the participant should experience a lower degree of masking of the real environment and other road users like cyclists and pedestrians caused by the displayed AR content. It might happen though that the mental workload of the driver is higher while using the dotted fishbones due to the fact that its dotted fishbones might be harder to recognize and interpret than the solid lines [25].

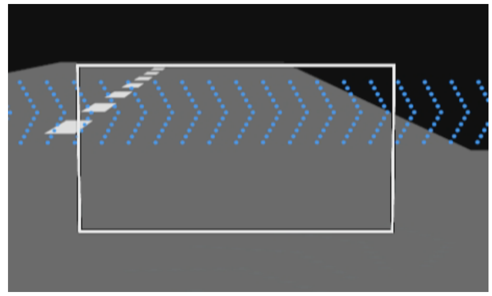

Figure 6. Middle marker of the dotted fishbone concept

3.3 Adaption of the Concepts

After the definition of the two navigation concepts that are compared in the field study, two test drives were conducted together with experts in the field of AR HUD concept design to further improve both concepts and their behaviour. The parameters that were adapted together with the corresponding values is listed in the Table below:

Parameter	**Value (meters)**
Entry marker length	7
Entry marker fade-in distance	90
Entry marker curve	5
Middle marker fade-in distance	50

Table 1. Parameters adapted for both concepts after conducting further test drives

The fade-in distance of a specific marker can be seen as the distance to the manoeuvre point in the map. Sometimes, though it is not possible to display the *entry marker* 90 meters in advance of the turn-off point as the required information cannot always be provided by the road map data that soon. In that case, the *entry marker* is shown as soon as the required data is available. Another change that was made because of the conducted test drives was the integration of an initial slanted position of the *entry marker* (tilt = 15°) to achieve a better visibility in larger distances. Furthermore, the tilt of the *entry marker* is reduced to 0° in a steady way, the closer the driver gets to the corresponding fade-out event. A further concept adaption that was implemented was the removal of the *exit marker*. Due to imprecise positioning data, the component could hardly ever be displayed at the right position and thus could not provide a real added value. Another idea that was evaluated due to the imprecise positioning data was the replacement of the contact analogue *middle marker* by a static one. After conducting test drives with experts of both fields, AR and interaction design, this idea was rejected. The reason was that the experts still preferred a pure contact analogue variant of the navigation concepts.

4. Experiment

In this section, the hypotheses for the empirical study are introduced and information about study participants as well as the test track is given. Furthermore, this section contains information regarding the test environment and the corresponding predevelopment software as well as an explanation of the study procedure. This study was designed and conducted according to ethical guidelines for experiments with test persons in the real traffic.

4.1 Hypotheses

The goal of this field study was to examine whether masking effects can be reduced by the application of *Gestalt Principles* while maintaining the quality of the information displayed in the HUD so that users would still understand the shown navigation cues. Also, we wanted to measure the drivers' subjective workload to evaluate whether the integration of dotted fishbones and their more difficult recognisability actually causes a significant increase in perceived workload compared to the solid fishbones. To be able to further assess the new navigation concept variants, to get insight into the user's more general opinion, and to derive ideas on possible rework or improvement, user experience and subjective assessment were evaluated in terms of *design*, *positioning*, masking, intuitiveness, and *distraction.*

Thus, four hypotheses were formulated for the conducted field study:

- H1: *The two navigation concepts differ in terms of navigation errors.*
- H2: *The driver's subjective workload is significantly higher for the dotted fishbone concept.*
- H3: *The two navigation concepts differ in terms of subjective assessment.*
- H4: *The two navigation concepts differ in terms of user experience.*

4.2 Participants

Because the used test vehicle was a prototype, only employees of the major car manufacturer were allowed to drive the car. As subjects, only experts in fields that are relevant for the development of an AR HUD (Interaction design, AR, HUD, design, and sales) were chosen. Thereby, we wanted to get valuable subjective expert knowledge about the development of future navigation concepts and the degree of masking effects caused by the examined navigation variants.

In total, 26 participants took part in the study while datasets of 2 test persons had to be removed due to technical problems. From the remaining 24 participants, 5 were female and 19 male ranging in height from 1.56 meters to 1.90 meters with M = 1.79 meters and SD = 8.86. They ranged in age from 22 to 51 years with M = 34.71 and SD = 8.11 and were holding a valid driving license. The shortest length of the driver's license possession was 4 years, whereas the longest was 31 years. The average amount of the approximate number of driven kilometres in the last twelve months was 20250 with a standard deviation of 10279.78. Every participant had completed a special driving safety training prior to the experiment to be allowed to drive the test vehicle used for this field study. This is only available for employees of the major car manufacturer. All drivers had experience with conventional navigation solutions for smartphone or integrated in a vehicle and used them regularly. Every driver has used a static HUD before but only one participant has one in his private car. The participant's attitude toward HUDs in general was positive. All participants were tested individually and gave their written consent to participate in the experiment.

4.3 Test Track

The track had to be defined in a way that the results of the test drives could give information regarding the suitability of the two navigation concepts as well as the degree of covering traffic objects. For this reason, longer motorway or country road sections with only a little amount of turns were not included. Another important criterion was that the traffic density stayed consistent during the time in which the test drives were conducted (between 9:00 *am* and 16:00 *pm*). Finally, a track was chosen that contained almost exclusively streets that are categorized as *level 5* by HERE [20] which means most of the time drivers had a tempo limit of 30 *kph*. The starting point was around 2.5 *km* away from the manufacturer's plant. That 2.5 *km* were used as a short acclimatisation period for the participants to get used to the test vehicle. After multiple test drives a track was chosen that had a length of 2.5 *km* and contained 9 right as well as 9 left turns and one manoeuvre where the driver had to go straight (see Figure 8). Also, a little roundabout was on the test track that had to be passed straight. As the test drive took place in residential areas with almost exclusively streets with a speed limit of 30 *kph*, one could expect road participants like bicyclists and pedestrians as well as cars. This was useful for the evaluation of the influence of masking caused by AR content. The participants had to drive the route two times, one time with each AR HUD navigation concept which took them around 20 to 25 minutes in total.

For the test vehicle's navigation system, it was necessary to create a file consisting of an array of the test route's waypoints (longitude and latitude). With the help of those waypoints, the car showed the predefined manoeuvres of the test track even though a free navigation or redirection would have been possible with this system as well.

4.4 Test Environment

As the study took place in real traffic, a suitable test vehicle with integrated AR HUD was used. Figure 7 shows the interface of the test vehicle showing an exemplary middle marker of the dotted fishbone concept. Furthermore, a predevelopment environment software was created for the prototype car. It includes the so-called *Robot Operating System* (ROS), which is a set of software libraries and tools that are used to synchronize the vehicle's sensor and bus data (GPS, accelerometer, gyroscope, and *FlexRay*). Also, a map interface was included, provided by *HERE maps* to access current map data online. With the help of the toolkit *QT*, a graphical user interface for AR HUD was created and furthermore, the *Open Graphics Library* (Open GL) was used as rendering pipeline. For the AR content creation, the 3D tool *Autodesk Maya* was used together with the image editing software *Photoshop*.

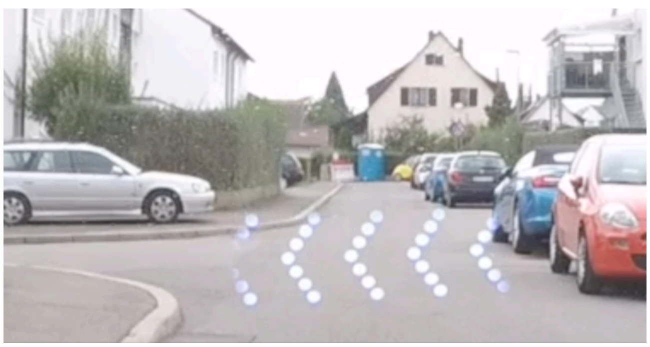

Figure 7. The interface of the test vehicle showing an exemplary middle marker of then dotted fishbone concept.

4.5 Procedure

One of the few studies in real traffic was conducted by Pfannmüller [28] to compare a conventional HUD with an AR HUD with the help of the use case *navigation*. Even though there were limitations like the usage of a different test vehicle for each HUD type and no possibility of free navigation with the prototype car the AR HUD was implemented in, this study can be used for orientation.

After getting a short introduction to the test vehicle, the participants were allowed to adjust the positions of the driver seat, interior, and exterior mirrors. Driver assistance systems like *lane departure warning system* or *blind spot monitor* were not available in the car. Furthermore, the usage of *adaptive cruise control* (ACC) with steering assistant was not allowed as this might have had an influence on the driver's workload. After taking a short practice route to familiarize with the prototype vehicle, the participants had to stop at a parking area next to the starting point of the test track and had to sign a consent form. To get a first impression of the size and display quality of the integrated AR HUD, three different test images were shown. The first one consisted of black and white squares to show the size of the FOV. The second one contained various colour gradients to get a further impression of the display quality. The final one showed an exemplary navigation arrow that was used to calibrate the HUD along the y-axis. For this, a marker on a building at the parking area was used.

While the examiner started the test environment, the drivers filled out a questionnaire covering demographical data, driving experience, and experience with HUDs in general. The weather conditions were logged by the examiner. In the following, the subjects were given oral instructions for the experiment and were told to think aloud during the drives. Every participant had to drive the test track twice with identical test procedures for both AR HUD navigation concepts. Since the driving route was identical for both concepts, the order in which the two navigation variants were used was counterbalanced across participants to mitigate the influence of training effects on the performance measures used. If drivers were insecure about navigational cues they were asked to slow down before taking a turn and to tell the examiner in which direction the navigational cue was leading them. The experimenter took a seat on the passenger seat next to the driver while a second person was sitting on the rear bench behind the examiner to log special incidents like navigation errors and system malfunctions. Additionally, a *GoPro* dashcam was integrated in the test vehicle to record audio data together with a video from each drive.

After finishing the route, participants filled in the *User Experience Questionnaire* (UEQ) to measure the user experience and the *Driving Activity Load Index* (DALI), a tool designed to evaluate the driver's mental workload. The UEQ measures the user experience of interactive products for six different categories. The driver is asked to give answers to each of the 26 items on a 7-point Likert scale with bipolar word pairs on each end [21]. The DALI which was designed by Pauzié [26] is a short scale questionnaire that is based on the NASA-TLX [19] and contains one item for each of the following factors: global attentional demand, visual demand, auditory demand, stress, temporal demand, and distraction. For this experiment, however, the factor auditory demand has been removed due to not being relevant. The sensitivity of the instrument was validated in multiple studies [26, 27]. In addition, a self-designed questionnaire to assess different aspects of each concept like design, degree of masking, distraction, and positioning accuracy was used. The questionnaire was based on a tool used by Pfannmüller [28] for a field study to compare the use case *navigation* in a contact analogue and static head-up display. Open questions were used to ask the drivers what they liked or disliked about the navigation concepts and what they would improve. After the second drive, the participants had to compare the two concepts and answer whether they had a favourite and if they could explain, why.

5. Results

This section contains a summary of the study results, containing the navigational errors, the UEQ, the DALI, and the questionnaire for subjective assessment. Furthermore, feedback the experts gave in the open questions is described. Wilcoxon Signed-rank tests were conducted to analyse the questionnaire data and the non-normally distributed navigational error data. The alpha level was set to .05. All analyses were performed in SPSS (version 24.0).

5.1 Navigational Errors

Thirty-three navigational errors were made in total, of which most (87.87%) happened at three turn-off points. These points are marked in Figure 8. Eight of the 33 navigational errors (24.24%) happened at turn-off point 1 which represents a little roundabout. More than half (51.51%) of the navigational errors were recorded at turn-off point 2, a straight manoeuvre crossing at an intersection (see Figure 8, marker 1). Lastly, four navigational errors (12.12%) were made at turn point 3. The average navigational errors made per subject were quite similar for the solid fishbones (M = 0.71, SD = 0.95) and the dotted fishbones (M = 0.67, SD = 0.70). A Wilcoxon Signed-rank test indicated that there was no significant difference between the concepts in the navigational errors made per subject (Z = - 0.144, p = .886). However, further analysis revealed that there was a significant learning effect regarding navigational errors made per subject when comparing the first time (M = 1.13, SD = 0.92) and the second time (M = 0.3, SD = 0.47) the participants drove around the test track (Z = - 3.28, p = .001).

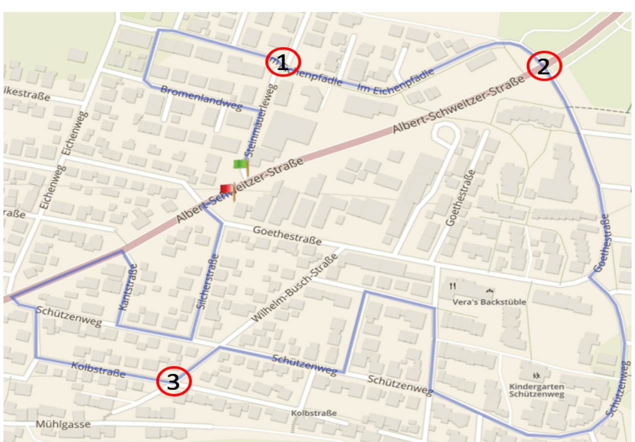

Figure 8. Turn-off points with frequent occurrence of navigation errors [16]

5.2 User Experience Questionnaire (UEQ)

The user experience was measured with the UEQ. There are no significant differences between the two concepts for any category (see Table 2). There is a slight trend for the solid fishbone concept to be rated higher with respect to *perspicuity*, *dependability* and *stimulation* as well as for the dotted fishbone concept to be rated as more of a *novelty*. The analysis regarding order effects revealed that the first navigation concept (M = 1.35, SD = 0.88) participants saw, is rated significantly higher in the category *novelty* compared to the second navigation concept (M = .89, SD = 0.78), Z = - 2.1, p = *.04.*

Category	M (solid)	M (dotted)	Z	p
Attractiveness	0.96	0.93	-0.05	.96
Perspicuity	1.57	1.08	-1.55	.12
Efficiency	1.06	0.97	-0.18	.86
Dependability	1.1	0.9	-1.21	.23
Stimulation	1.34	1.09	-1.35	.18
Novelty	1.0	1.24	-1.14	.25

Table 2. Results (mean values) of UEQ per concept.

5.3 Driving Activity Load Index (DALI)

To assess the subjective workload during the drive the DALI was used. The driver had to give an answer for each item on a 6-point Likert scale from 0 (low) to 5 (high). Neither the single-item analysis nor a global mean analysis revealed significant differences between the two concepts in terms of mental workload and there was no significant order effect on any of the DALI categories either.

5.4 Questionnaire for Subjective Assessment

The subjective assessment of the two navigation concepts for the categories *design*, *positioning*, masking, intuitiveness, and *distraction* was obtained using a self-designed questionnaire that consisted of 18 questions. The items use a 6-point Likert scale or German school grades (1 = best, 6 = worst) to assess those topics and were designed for this field study. This section contains the results of the items with significant differences only.

Question 1.2 and 1.4 deal with the display (geometrical form) of the navigation concept. The results are shown in Table 3:

Semantic differentials	M (solid)	M (dotted)	Z	p
1.2: Too wide (1) - too narrow (6)	2.96	2.38	-2.58	.01
1.4: Too dominant (1) – too subtle (6)	2.33	2.83	-2.08	.04

Table 3. Results (mean values) of questions addressing the colour design of the navigation concepts.

In question 2.2, 2.3 and 2.4 the participants had to assess the colour design of the navigation hints. The results are shown in Table 4:

Semantic differentials	M (solid)	M (dotted)	Z	p
2.2: Too subtle (1) - too intrusive (6)	3.67	3.13	-2.28	.02
2.3: Too bright (1) – too dark (6)	3.13	3.46	-2.31	.02
2.4: Too covering (1) – too transparent (6)	2.67	3.54	-3.28	< .01

Table 4. Results (mean values) of questions addressing the colour design of the navigation concepts.

The next four questions with a significant difference consisted of a 6-point Likert scale with the endpoints *strongly disagree* (value = 1) and *strongly agree* (value = 6).

Question	M (solid)	M (dotted)	Z	p
7: I found it easy to recognize and interpreted the displayed navigation hints.	4.92	4.38	-2.3	.02
8: The masking of the real world caused by AR content was disturbing.	3.25	2.17	-2.13	.03
10: I could perceive the displayed AR HUD content well under the experimental conditions.	5.58	4.79	-2.68	< .01
11: In my opinion the concept covered too much of the real environment.	3.38	2.13	-2.56	.01

Table 5. Results (mean values) of questions with a 6-point Likert scale.

Questions 8 and 11 address the degree of masking and both show a significant difference among the shown navigation concepts. In the last question the participants had to choose which concept they prefer in terms of masking of the real environment. 16 experts said that they preferred the dotted fishbones, whereas 7 said they would choose the solid ones. One participant did not have a favourite.

5.5 Open Questions

Besides the standardized and self-designed questionnaires, the subjects had to answer a number of open questions after each drive. The experts gave positive and negative feedback concerning the two concepts and were asked if they had any suggestions for improvements. Furthermore, they were asked whether a combination of contact analogue and static content is a meaningful idea for a navigation concept for AR HUD and how this could be realized. After driving with both concepts, the participants were asked which concept they would prefer and why. Finally, they were asked which concept covered less of the real environment and why. The evaluation was executed according to the *qualitative content analysis* by Mayring et al. [24] and is based on the inductive development of categories.

In the following, positive and negative feedback the experts gave on the two concepts, is introduced, together with feedback that is valid for both concepts. For the solid fishbones 14 participants stated that they like its intuitiveness and clearness. Furthermore, 5 experts said that they are easy to recognize also in comparison to the dotted fishbones. Another characteristic that people liked about the fishbone concept was that in case of being cut off by the limited FOV one can still recognize the direction in which the navigation cue points to (mentioned by 2 subjects). Also, 2 drivers rated this concept as better designed and more contemporary than the dotted fishbones. Furthermore, 1 expert stated that he or she had the impression that the solid fishbones keep the driver awake and another participant said that due to its intuitiveness the navigation hint gives a feeling of safety.

The *dotted fishbone concept* was rated as intuitive and clear as well (13 participants) and 11 experts mentioned that it covers less of the real-world environment. Five participants thought that the concept with the dotted fishbones gives the impression of being more valuable as well as more delicate and 4 subjects rated the concept as innovative. In addition, 3 experts appreciated the concept's discreet design and 2 subjects said that they perceived the cutting of the AR content, caused by the limited FOV, as less disturbing. Finally, 1 expert mentioned that he or she liked the 3D experience that he or she perceived with the dotted fishbones when the positioning was accurate.

There was feedback that was valid for *both* concepts and for that reason it made sense to assign these categories to a separate group. Seven participants said that the notifications are pleasant in terms of their colour scheme. Furthermore, 5 participants stated that they liked the contact analogue positioning of the navigation cues and 5 experts mentioned that the fade-in timing of the fishbones is good. Three of the subjects appreciated the fact that it is no longer necessary to avert the view in order to see navigation hints. Additionally, 3 participants liked that their eyes-off-the-road time was decreasing as the AR content was placed in their primary FOV.

Besides positive feedback, negative aspects have been mentioned by the experts as well. Especially the size of the *solid fishbone concept* and its dominance are described to have a negative impact, especially when being close to a manoeuvre point (mentioned by 17 subjects). Further, 10 subjects criticized the high degree of masking of the real environment caused by the fishbones. Another issue that was mentioned by 4 people is that when the AR content gets trimmed too much it's not possible to interpret the shown turn direction anymore. Four experts mentioned that their stress level was increasing and they also had to concentrate more while driving with the solid fishbones. Two participants mentioned that they experienced a strong flickering of the shown AR content while driving with this navigation concept. Finally, 2 participants stated that the individual fishbones are too big.

For the *dotted fishbone concept*, 12 experts criticized the fact that it is not possible to interpret the turning direction when the AR cues were cut off. The reason for that is that the drivers can only see single dots that cannot be put together to a fishbone-shape anymore. Eight participants criticized that this navigation indication claimed a higher amount of cognitive resources and distracts the driver more. Furthermore, 7 experts stated that the navigation cues of the *dotted fishbone concept* are hard to recognize and 7 participants mentioned that they are too dominant. An issue that was criticized by 4 people was the fact that the human has to reconstruct the single dots back together to a fishbone first before recognizing the shape which costs mental effort. In addition, 4 experts said that they got disturbed by the fact that the AR content gets cut off due to the limited FOV. Also, in case of the dotted fishbones, it was mentioned 3 times that drivers experienced a strong flickering of the AR content.

There was negative feedback that was valid for both concepts and that is why those categories were again assigned to a separate group. Especially the sometimes-imprecise positioning of the navigation cues was criticized by 18 experts and 7 subjects mentioned that the transition between *entry marker* and *middle marker* is too abrupt and should be smoother. Six participants stated that the *entry marker* should be displayed longer while 3 experts suggested to increase its size to enhance visibility and comprehensibility. Finally, 2 subjects mentioned that the entry marker should also be shown earlier.

Besides the negative and positive aspects, the subjects were asked to state improvements for both concepts. For improving the *solid fishbone concept*, 6 participants suggested to integrate the possibility to adjust the level of transparency or display outlines only. To soften the design of the navigation cues of the *solid fishbone concept*, 5 subjects were thinking about round edges for every single element of the cues. To avoid masking of other traffic participants, 2 experts had the idea to hide the AR content in case of oncoming traffic and 2 subjects mentioned that they would like the idea of having additional textual indications to improve the comprehensibility of the navigation concept. To achieve a better integration in the real environment, 2 subjects had the idea of adding animation and another participant thought about a more precise lower edge of the navigation arrow by using e.g. shadows.

Improvements solely mentioned for the *dotted fishbone concept* were given by suggesting a more transparent display of the single circles (mentioned by 6 subjects). Additionally, 2 subjects suggested to raise the *entry marker* up in order to create a better flow along the street. In case of a strong cut of the AR content due to the limited FOV, 2 experts had the idea of using a different graphic rendition and 1 expert wanted a softer transition between *entry marker* and *middle marker*. Another expert stated that the avoidance of the effect which makes it look like driving through the *middle marker* would be an improvement.

Beside this, the subjects made suggestions concerning both concepts. These include the possibility of adjusting the displayed concept concerning its size, the number of elements, and the colour, mentioned by 9 subjects for the *solid fishbone concept* and by 15 subjects for the dotted fishbones. Further, an improvement of the notification's positioning was stated, 7 votes for the solid fishbones and 9 votes for the dotted fishbones. The experts also suggested to integrate a pre-indication which includes the direction of the upcoming manoeuvre and the distance to it (6 votes for the solid fishbones and 4 votes for the dotted fishbones). A similar idea that was mentioned 2 times for the solid fishbones and 2 times for the dotted fishbones is to integrate a permanent notification that shows that the AR HUD navigation is still running. This could be realised with the help of a static route indicator. Another suggestion was to extend the display time of the *entry marker* which was mentioned by 3 experts in case of the solid fishbones and by 2 experts in case of the dotted fishbones. The combination of *entry* and *middle marker* is an improvement given by 3 subjects for the solid fishbones and by 1 subject for the dotted ones. Finally, 2 participants suggested to integrate the possibility to make the brightness of the current navigation concept adjustable for the future customer.

When the subjects were asked to state how a combination of contact analogue and static content in one notification could look like they answered as follows: One idea was to display driving assistance information like current speed, traffic signs or ACC in a separate status bar (9 votes for the solid fishbones and 9 votes for the dotted fishbones). For both concepts, they desired that the navigation cues could be extended with static content which should be displayed situationally only (mentioned 9 times for the solid fishbones and 6 times for the dotted ones). Another suggestion was a static pre-indication showing the upcoming manoeuvre and the distance to it, mentioned 7 times for the solid fishbones and 7 times for the dotted fishbones. Another idea was to show static navigation cues in case of the contact analogue content being cut too much (1 vote for the *solid fishbone concept* and 1 vote for the *dotted fishbone concept*). Also, the integration of the estimated arrival time was stated one time in case of the solid fishbones and one time in case of the dotted fishbones. Finally, the participants mentioned that it would be helpful to integrate a static direction icon to show the driver that the system is still active (1 vote for the solid fishbones and 1 vote for the dotted fishbones).

When asked which concept they preferred and for what main reasons, the results showed a slight preference towards the solid fishbones. In total the solid fishbones got 12 votes, the dotted fishbones got 9, and 3 experts had no favourite. The participants gave one or more reasons why they chose a certain concept. In case of the *solid fishbone concept*, 6 subjects mentioned that it is easier to interpret, especially when the AR content is cut off strongly due to the limited FOV and only parts of the fishbones remain visible. Three participants had the opinion that the solid fishbones have a better design and 1 expert stated that the lower cognitive load is one of the key reasons why he or she prefers them. One participant experienced less flickering of the displayed AR content while driving with the solid fishbones and another subject said that this concept is less distracting. Another driver mentioned that the solid fishbones remind him of objects that are already known and 1 participant stated that they made her less dizzy during a turning manoeuvre. For the *dotted fishbone concept*, 6 participants gave the fact of less masking as one of their main reason for preferring it. Two experts said that their cognitive load was lower and also, the design was preferred two times. For 1 subject the concept's good integration in the real environment was a key reason for choosing it and another driver found that it was easier to interpret, especially when the AR content is cut off strongly. Finally, 1 expert mentioned that the enhanced 3D experience is a strong benefit of the dotted fishbones.

6. Discussion and Conclusion

In the current field study, two different navigation concepts for AR HUD were compared in a prototype car with a suitable test environment. The results show that the amount of navigation errors made with each navigation concept was similar. Thus, H1: *The two navigation concepts differ in terms of navigation errors* has to be rejected. Most of the navigation errors were made in situations where the positioning of the displayed AR content was inaccurate. Furthermore, the drivers would like to have navigation cues at the roundabout and misunderstood the *middle marker* standing on the edge showing that the driver had to continue straight.

No significant differences could be found regarding the driver's subjective workload which was examined with the DALI questionnaire. Thus, H2: *The driver's subjective workload is significantly higher for the dotted fishbone concept* has to be rejected. However, in the open questions, it was mentioned multiple times that the concept with the dotted fishbones increases the cognitive load and is distracting. Fewer experts mentioned this fact for the solid fishbones. Therefore, one can recognize a tendency towards a higher cognitive load while driving with dotted fishbones.

The self-created questionnaire containing questions with 6-point Likert scales and German school grades were made to compare the navigation concepts with regard to design, positioning, and distraction. H3: *The two navigation concepts differ in terms of subjective assessment* can be accepted partly as not all of the questions showed significant differences. In total, the *solid fishbone concept* was rated as significantly wider, more dominant, more intrusive, brighter, and has a higher degree of masking. Furthermore, the solid fishbones were rated as significantly easier to recognize and to interpret and also easier to percept. In addition, the participants believed that the solid fishbones cover more of the real world and they also stated that the masking of the real environment is more disturbing while driving with the solid fishbones. In addition, when asked which contact analogue navigation concept they prefer in terms of masking in the open questions part, the majority of the experts said, they would choose the dotted fishbones, supporting the results of the subjective assessment questionnaire analysis.

With regard to user experience, the UEQ did not show any significant differences between the two concepts, so H4: *The two navigation concepts differ in terms of user experience* has to be rejected as well.

In the foreseeable future, developers will still have to deal with technical limitations like e.g. inaccurate road map or sensor data or package limitations. Therefore, it is necessary to create robust and flexible UI concepts. In this study, an open questions part was included to collect expert knowledge in terms of navigation concepts for an AR HUD which can be used for future concept development. The extensive findings contain positive and negative feedback for the field study concepts examined, suggestions for improvements, and the combination of static and contact analogue information in the AR HUD. Finally, test persons also explained which concept they liked more and for what main reasons.

As some participants had the impression that the AR content was flickering, one of them was asked to look at screenshots of the navigation concepts and to check whether this phenomenon occurs as well. In the laboratory setup a different head-up display hardware was used. As the participant couldn't perceive any flickering it can be speculated that the used HUD hardware or predevelopment software could have been responsible the effect.

To put it in a nutshell, the usage of *Gestalt Principles* to reduce masking caused by navigation cues can be seen as promising solution when a lot of virtual information from different DASs that would cause a lot of masking needs to be displayed in the driver's primary FOV. Nonetheless, developers need to make sure that drivers are still able to recognize and process the shown information in a sufficient way.

7. Limitations and Future Work

There are several limitations in this field study. First of all, the group of participants consisted of experts only which was predetermined because of the test vehicle that had to be used. Because of that, the data is very valuable from a development perspective. However, it is not transferable to the general population. Future studies could focus on participants with no expert knowledge. It should be kept in mind, that subjects might be amazed by the AR integration when using the AR HUD technology for the first time. This could lead to some bias in the results. We counterbalanced the test order to mitigate those effects. However, because the AR technology as such is not available in cars' HUD yet, it is difficult to find participants without expert knowledge but experience in AR HUD. Because the study was conducted in the real-traffic there were non-controllable confounding factors, such as the weather, slight differences in traffic density, pedestrians or cyclists and other specific events.

Even though the concepts were only evaluated in one specific car, this field study can be seen as one of the first approaches to investigate navigation concepts for an AR HUD in the real traffic. Also, masking effects could be further examined by integrating objective measurements in the study like targets placed on a private test track. For this study, this was not possible as it was conducted in a real traffic scenario.

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REFERENCES

[1] P. Atchley, A. F. Kramer, G. J. Andersen and J. Theeuwes. 1997. Spatial cuing in a stereoscopic display: Evidence for a "depth-aware" attentional focus. *Psychonomic Bulletin & Review* 4, 4: 524-529. https://doi.org/10.3758/BF03214343

[2] R. T. Azuma. 1997. A Survey of Augmented Reality. *Teleoperators and Virtual Environments* 6, 4: 355-385. https://doi.org/10.1162/pres.1997.6.4.355

[3] K. Bengler, K. Dietmayer, B. Faerber, M. Maurer, C. Stiller and H. Winner. 2014. Three Decades of Driver Assistance Systems: Review and Future Perspectives. *IEEE Intelligent Transportation Systems Magazine 6*, 4: 6–22. https://doi.org/10.1109/MITS.2014.2336271

[4] K. Bengler, M. Götze, L. Pfannmüller, and A. Zaindl. 2015. To See or not to See - Innovative Display Technologies as Enablers for Ergonomic Cockpit Concepts. Ergonomic Requirements, Future Mobility, Future Functionality. In *Proceedings of the electronic displays Conference.*

[5] H. Bubb. 1975. *Untersuchungen über die Anzeige des Bremsweges im Fahrzeug.* Doctoral Dissertation. Technical University of Munich, Munich, GER.

[6] H. Bubb. 2015. Systemergonomie des Fahrzeugs. In *Automobilergonomie*, H. Bubb, K. Bengler, R. E. Grünen, and M. Vollrath (eds.). Springer Fachmedien Wiesbaden, Wiesbaden, GER, 1-25. https://doi.org/10.1007/978-3-8348-2297-0_6

[7] J. C. Byers, A. C. Bittner, and S. G. Hill. 1989. Traditional and raw task load index (TLX) correlations: Are paired comparisons necessary? In *Advances in Industrial Ergonomics and Safety,* A. Mital (ed.). Taylor & Francis, London, UK, 481-485.

[8] Commission of the European Communities. 2008. *Commission Recommendation of 26 May 2008 on safe and efficient in-vehicle information and communication systems: update of the European Statement of Principles on human machine interface. No. C (2008) 1742.* Brussels: The Commission of the European Communities

[9] Continental AG. 2017. Head-up-Displays. Retrieved September 12, 2018 from https://www.continental-automotive.com/de-DE/Passenger-Cars/Technology-Trends/Holistic-Human-Machine-Interface-(1)/Head-Up-Displays

[10] DIN EN 894-1. 2009. *Sicherheit von Maschinen – Ergonomische Anforderungen an die Gestaltung von Anzeigen und Stellteilen – Teil 1: Allgemeine Leitsätze für Benutzer-Interaktion mit Anzeigen und Stellteilen; Deutsche Fassung EN 894-1:1997+A1:2008.* Berlin: DIN Deutsches Institut für Normung e.V., Beuth Verlag.

[11] DIN EN ISO 9241-10. 1996. *Ergonomische Anforderungen für Bürotätigkeiten mit Bildschirmgeräten - Teil 10: Grundsätze der Dialoggestaltung.* Berlin: DIN Deutsches Institut für Normung e.V., Beuth Verlag.

[12] DIN EN ISO 15005. 2002. *Straßenfahrzeuge - Ergonomische Aspekte von Fahrerinformations- und -assistenzsystemen - Grundsätze und Prüfverfahren des Dialogmanagements.* Berlin: DIN Deutsches Institut für Normung e.V., Beuth Verlag.

[13] DIN EN ISO 15008. 2009. *Straßenfahrzeuge - Ergonomische Aspekte von Fahrerinformations- und Assistenzsystemen – Anforderungen und Bewertungsmethoden der visuellen Informationsdarstellung im Fahrzeug.* Berlin: DIN Deutsches Institut für Normung e.V., Beuth Verlag.

[14] C. Furmanski, R. Azuma, and M. Daily. 2002. Augmented-reality visualizations guided by cognition: Perceptual heuristics for combining visible and obscured information. In *Proceedings of the International Symposium on Mixed and Augmented Reality* (ISMAR '02), 215-224. https://doi.org/10.1109/ISMAR.2002.1115091

[15] K. Gish and Loren Staplin. 1995. *Human Factors Aspects of Using Head Up Displays in Automobiles: A Review of the Literature* (Report No. DOT HS 808 320). National Highway Traffic Safety Administration, U.S. Department of Transportation.

[16] GPSies. 2018. GPSies: Tracks for Vagabonds. Retrieved September 18, 2018 from https://www.gpsies.com

[17] C. Grabowksi, T. Zamojdo and J. C. Clegg. 2011. Virtual Cable TM. Retrieved September 12, 2018 from www.mvs.net

[18] R. Häuslschmid, B. Pfleging, and F. Alt. 2016. A Design Space to Support the Development of Windshield Applications for the Car. In *Proceedings of the 2016 CHI Conference on Human Factors in Computing Systems* (CHI '16), 5076–5091. http://doi.acm.org/10.1145/2858036.2858336

[19] S. G. Hart and L. E. Staveland. 1986. *NASA Task Load Index (TLX) V1.0 User's Manual.* Ames Research Center.

[20] HERE. 2018. Traffic API: FunctionalClassType. Retrieved September 12, 2018 from https://developer.here.com/documentation/traffic/topics/resource-type-functional-class.html

[21] A. Hinderks, M. Schrepp, and J. Thomaschewski. 2018. *UEQ – User Experience Questionnaire.* Retrieved September 12, 2018 from http://www.ueq-online.org/

[22] B. Israel. 2013. *Potenziale eines kontaktanalogen Head-up Displays für den Serieneinsatz.* Doctoral Dissertation. Technical University of Munich, Munich, GER.

[23] M. A. Livingston, J. E. Swan, J. L. Gabbard, T. H. Hoellerer, D. Hix, S. J. Julier, Y. Baillot, and D. Brown. 2003. Resolving multiple occluded layers in augmented reality. In *Proceedings of the Second IEEE and ACM International Symposium on Mixed and Augmented Reality* (ISMAR '03), 56 – 65. https://doi.org/10.1109/ISMAR.2003.1240688

[24] P. Mayring and T. Fenzl. 2014. Qualitative Inhaltsanalyse. In *Handbuch Methoden der empirischen Sozialforschung*, N. Baur and J. Blasius (eds.). Springer VS, Wiesbaden, GER, 543-556. https://doi.org/10.1007/978-3-531-18939-0_38

[25] W. Narzt, G. Pomberger, A. Ferscha, D. Kolb, R. Mueller, J. Wieghardt, H. Hoertner, and C. Lindinger. 2006. Augmented reality navigation systems. *Universal Access in the Information Society 4,* 3: 177-187. https://doi.org/10.1007/s10209-005-0017-5

[26] A. Pauzié. 2008. A method to assess the driver mental workload: The driving activity load index (DALI). *IET Intelligent Transport Systems* 2, 4: 315-322. https://doi.org/10.1049/iet-its:20080023

[27] A. Pauzié. 2014. Evaluation of the driver's mental workload: a necessity in a perspective of in-vehicle system design for road safety improvement. *Cognition, Technology & Work* 16, 3: 299-302. https://doi.org/10.1007/s10111-014-0276-0

[28] L. Pfannmüller. 2017. *Anzeigekonzepte für ein kontaktanaloges Head-up Display.* Doctoral dissertation. Technical University of Munich, Munich, GER.

[29] L. Pfannmüller, M. Walter, and K. Bengler. 2015. Lead me the right way?! The impact of position accuracy of augmented reality navigation arrows in a contact analog head-up display on driving performance, workload, and usability. In *Proceedings of the 19th Triennial Congress of the International Ergonomics Association (IEA) 2015.*

[30] T. Ross, K. Midtland, M. Fuchs, A. Pauzié, A. Engert, B. Duncan, M. Vernet, H. Peters, G. Burnett, and A. May. 1996. *HARDIE Design Guidelines Handbook: Human Factors Guidelines for Information Presentation by ATT Systems.* Brussels: Commission of the European Communities.

[31] M. Schneid. 2009. *Entwicklung und Erprobung eines kontaktanalogen Head-up Displays im Fahrzeug.* Doctoral dissertation. Technical University of Munich, Munich, GER.

[32] M. Yeh, J. L. Merlo, and C. D. Wickens. 2003. Head Up versus Head Down: The Costs of Imprecision, Unreliability, and Visual Clutter on Cue Effectiveness for Display Signaling. *Human Factors: The Journal of the Human Factors and Ergonomics Society,* 45, 3: 390-407. https://doi.org/10.1518/hfes.45.3.390.27249

[33] M. Yeh and C. D. Wickens. 2001. Attentional filtering in the design of electronic map displays: A comparison of color coding, intensity coding, and decluttering techniques. *Human Factors* 43, 4: 543-562. https://doi.org/10.1518/001872001775870359