

Ergonomic Design and Evaluation of Augmented Reality Based Cautionary Warnings for Driving Assistance in Urban Environments

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This paper covers currently investigated Augmented Reality (AR) applications in cars and examines different frame of reference for indication of occluded objects at intersections as well as differences between contact-analog and unregistered presentation. Four different AR schemes were tested against a baseline at two intersection scenarios implemented in a static driving simulator. In a contrast to studies that document the advantages of contact-analog over unregistered representations for direct indication of hazards, the results of this study show unambiguously that the most preferable schemes for showing occluded objects are schemes giving an overview of the whole situation, followed by a contact-analog annotation symbol.

INTRODUCTION

Information necessary to flawlessly accomplish the driving task is up to 90% perceived by the visual channel (Cohen & Hirsig, 1990). Inside modern vehicles, additional visual information is acquired through the instrument cluster in front of the driver and the central information display (CID) to the right of the driver. With steadily increasing implementation of Advanced Driving Assistant Systems (ADAS) and In-Vehicle Information Systems (IVIS), the ergonomic need for visual messages increases even further.

Head-Up Display (HUD) technology in a combination with Augmented Reality (AR) delivers a potential to overcome existing bottlenecks for increasing information needs in modern cars. A larger presentation area, now also covering the windshield can be used for information presentation. Contact-analog (Tönnis, 2008) virtual presentation schemes can get embedded in the real world and can become an additional component of safety systems. Information can be presented with respect to the location it references and can thus provide a situation dependent display. Besides, by displaying just relevant information concerning human-ADAS interaction, a currently disputed inadequate driver's understanding of ADAS functions can be improved.

HUDs reduce focal accommodation time and improve 'eyes on the road' time by reducing the number of glances to the in-vehicle area and they reduce display clutter (Burnett, 2003). However, AR presentations bear potential drawbacks such as the risk of occluding relevant objects of traffic as well as phenomena like perception tunneling and cognitive capture. Yet, it can be strongly argued that information presentation through this upcoming technology tends for the usage in time-critical environments.

AR presents an emerging research area, particularly concerning application in road traffic. However, technical feasibility of AR in vehicles and successful applications in other safety relevant fields such as medicine or military, justify the efforts of evaluating the potential of AR for ADAS applications. This paper gives an overview of contemporary research done in the field of AR for vehicles. To explore currently unrepresented questions whether AR can bring benefits for indication of visually concealed hazard objects, a study comparing four different presentation schemes was conducted in the static driving simulator.

AUGMENTED REALITY IN VEHICLES

There are two novelty implications of AR applications in vehicles: the possibility to integrate virtual 3D information into the driving scene and the possibility to present condensed information to the driver. The cutting-edge research regarding automotive AR deals with presentations of several types of relevant driving information such as: navigation assistance, traffic sign assistance, driving path and distance, warnings and ADAS feedback. Some of them will be briefly presented in this section.

Navigation. A potential benefit of contact-analog HUDs (CHUDs) lies in displaying navigation information in complex traffic situations (see Figure 1(a)). Another contact-analog navigation implementation, already available on the market is shown in Figure 1(b) (Virtual Cable, 2009). The virtual cable uses a volumetric display to create a true 3D image and superimposes it on the windscreen. Sato et al. (2006) use the whole windshield surface to project navigation information such as destination and distance combined with the direction which the driver should follow (see Figure 1(c)). However, due to the fixed focal distance of 1 m, this particular example cannot be classified as purely contact-analog information (Tönnis, 2008).

Traffic signs. Prevailing HUDs display current and desired speed, as well as the distance to the vehicle in front in an unregistered manner (see Figure 2). Currently ongoing ergonomic usability studies are working towards defining the best way to present the most relevant traffic signs. In usability studies performed by Huang (2005), speed limits, slippery road and 'no overtaking' traffic signs were selected as the most preferable.

Distance/Stop way. Depending on the situation, distances can be either shown as a stopping path or as the distance to the leading vehicle. Showing this information to the driver relieves him of evaluating the distance, which can be cognitively demanding. A usability study conducted by Marsteller (2004) has shown that, if symbolically presented, the distance is preferred to be seen in meters rather than seconds. The braking distance is also essential safety relevant information and is often inaccurately evaluated by car drivers. Assman (1985) made suggestions for a color encoded presentation of braking distance in a CHUD as it exhibits advantages of synthetic displays in the best manner (see Figure 3).

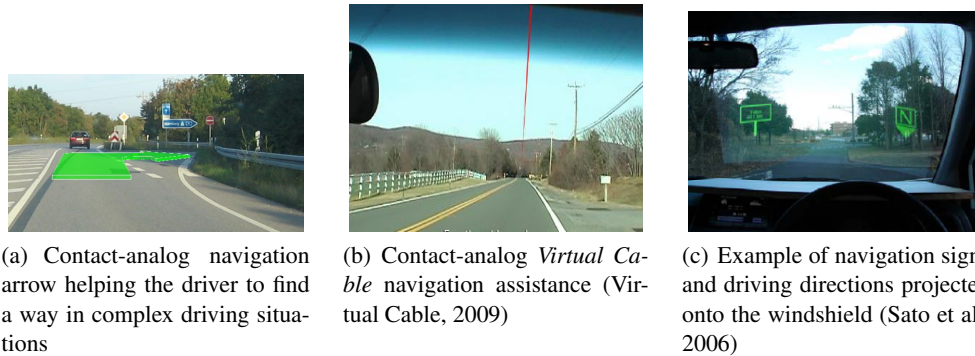
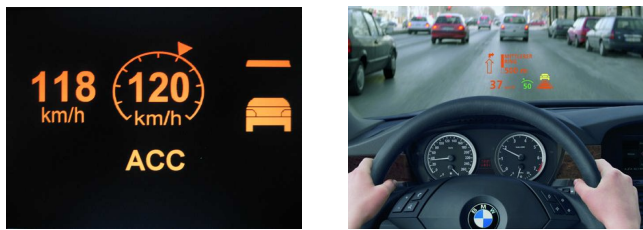


Figure 1. AR schemes for navigation assistance



(a) Traffic symbols for the current and desired speed and a distance to the leading vehicle
 (b) BMW HUD available on the market in Series 5

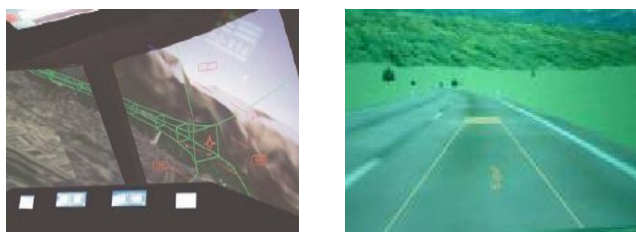
Figure 2. Traffic sign in prevailing HUDs



(a) In a driving simulator
 (b) In a car (Assman, 1985)

Figure 3. Braking distance bars showing stopping way of a vehicle

Drive path. Lane keeping can be especially critical for inexperienced drivers. In a usability study performed by Huang (2005), the lane guidance was very desirable especially for bad weather conditions and darkness. In the aviation industry such guidance is widely presented (see Figure 4(a)). Lane guidance is possible through AR technology in road vehicles as well (see Figure 4(b)). Tönnis et al. (2007) has found that the drive path improves lane keeping behavior by decreasing the lane deviation. An extension of this scheme can show the collision free area in intersections or construction sites.



(a) In airplanes (Mader, 2004)
 (b) In a driving simulator (Tönnis et al., 2007)

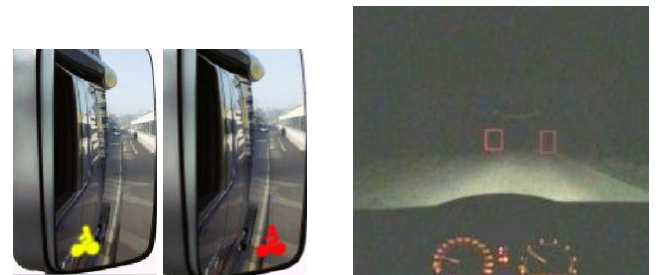
Figure 4. Presentation of pathways

Warnings. The potential of AR for the indication of warnings and possible hazards is of particular interest for the study presented in this paper. Green (1995) came up with

a list of hazards avoidable through warning information. The potential of AR presentation schemes for some of them is currently under investigation.

A kind of AR presentation was used as HMI interface for blind-spot assistance in MAN vehicles (Figure 5(a)). The system assists the truck drivers during right turns by detecting objects in the blind area of the truck and warns the driver with an appropriate symbol in the corresponding mirror.

Another AR application is a visualization for Night Vision Systems (see Figure 5(b)). The AR-based indication of pedestrians achieved an absolute advantage over standard unregistered symbols because it enabled effective and efficient information transfer (Bergmeier & Lange, 2008).



(a) AR application for Blind-spot assistance of MAN vehicles (Sauerbrey, 2001)
 (b) AR application for Night Vision system

Figure 5. Hazard avoidance systems

ADAS feedback. From an ergonomic point of view the activity level and the current operation mode of each ADAS should be known to the driver. In addition, the driver should also be familiar with important settings of some assistance systems such as, for instance, the ACC speed and distance setting, or the time-to-lane change of the Lane Departure Warning system. With ever-growing number of assistances and dependent information presentations, the danger of information overflow increases and prioritization becomes necessary (see Figure 6). One possibility can be placing information in the driver's field of view on the base of a probability for a human error. Ergonomic research has to determine a way to synthesize and integrate all such information.

ERGONOMIC ASPECTS OF INFORMATION DISPLAYS AND WARNINGS

AR extends the dimensionality of 2D objects with depth perception and in that way creates a mixed world: a world between reality and virtuality. This mixed world is changing the way humans perceive both of them. Not just depth perception, but also several more dimensions appear to be relevant in contrast to available information displays in vehicles (Tönnis et



Figure 6. Example of information overload

al., 2009): (1) continuous / discrete, (2) 2D / 3D, (3) contact-analog / unregistered presentation, (4) presentation in different frames of reference; (5) direct / indirect referencing of objects or situations and (6) location of presentation in relation to glance direction. As driving presents an exceptionally time-critical task, careful ergonomic design and evaluation of all these dimensions are crucial factors for AR effectivity.

AR being a new discipline, still requires investigation concerning adaptation of information presentation for the user. Special demands for analysis exist for time-critical tasks such as driving. Some aspects of AR schemes, like fatigue effects and optical quality have partially been researched as part of the ARVIKA project (Hamadou et al., 2002). However, these referred to production systems and Head Mounted Displays and not to driving and information presentation in HUDs. Important analysis relevant for application in vehicles has been conducted in the aviation industry, considering its relatively long experience and comparable issues and hazards. Contemporary ergonomic recommendations, developed for design and evaluation of automotive 2D information schemes should be independently investigated for AR applications. These need to be extended with guidelines and recommendations concerning AR-specific features. Current standards and ergonomic guidelines are therefore discussed in the subsequent.

Several standards regulate ergonomic aspects of visual presentation in vehicles:

- ISO 15008:2003, Road vehicles. Ergonomic aspects of transport information and control systems. Specifications and compliance procedures form in-vehicle visual presentation
- ISO 15005:2002, Road vehicles. Ergonomic aspects of transport information and control systems - Dialog management principles and compliance procedures
- ISO 16352:2005, Road vehicles. Ergonomic aspects of in-vehicle presentation for transport information and control systems – Warning systems

Additional general guidelines on how in-vehicle systems should be designed can be found in the EU recommendation paper (European Commission, 1999), in which among others, 'overall design principles' and 'information presentation principles' are presented. Recommendations concerning warnings are given in guidelines like the one from Green et al. (1994) or from Lerner (1996).

Yet, these principles are not adapted neither for currently available symbolic HUDs nor for the application of contact-analog AR schemes and cannot just be mapped directly to driving but have to be investigated intensively.

FORM OF PRESENTATION

An ergonomic classification of displays can be made on the basis of information content, form of presentation and display position. Primary questions concerning information

content are which information is to be presented, how much should be presented in a certain period of time and for how long. For the application of AR in vehicles, the most important issues are concerning the form of presentation. Existence of a virtual object in the real world can change the perception of both of them. It is necessary to understand how humans react to AR presentations and which aspects of perception must be understood to create the best possible visualization for the 3D world. These questions are also highly relevant for applications in medicine and military.

Different forms of presentation are discussed in detail in Tönnis et al. (2009). Here, just a short overview of important factors relevant for this study is given. The addressed issues, among others, are: which frame of reference supports situational awareness and spatial orientation better and to what extent, if at all, does a contact-analog display outperform spatially unregistered information presentation.

Frame of reference

For further understanding, the disputed terminology regarding frames of reference from an ergonomic and an AR point of view is discussed.

AR (with its origin in computer graphics) distinguishes between egocentric and exocentric presentation. Egocentric information in AR is an information that is fully embedded in the user's frame of reference. In contrast to this, exocentric information is shown from a non-user's point of view. The point of view, for instance, is rigidly mounted to the environment.

Ergonomic understanding of egocentric and exocentric information presentation is related to *pursuit* and *compensatory* displays (Bubb, 1993). Pursuit displays present exocentric information whereby compensatory displays are rigidly coupled to the user's frame of reference. Yet, they do not necessarily have to present the information from the user's point of view. According to this terminology a *Bird's eye view* in the orientation of the user is ergonomically egocentric, compensatory information, but from an AR point of view it is an exocentric presentation. Such disputed presentations, which are egocentric from an ergonomic point of view but exocentric from an AR point of view can often be classified to displays in *egomotion* (Colquhoun & Milgram, 2000): the display shows the view from an external position but rigidly follow the motion of the user.

The relevant question is, which frame of reference supports the fastest and the most intuitive comprehension of a situation. The solution depends on the required dependency between global and local situational awareness and on the type of object reference. The most appropriate frame of reference should be analyzed for each type of reference individually:

- indication of objects within driver's field of view
- indication of objects outside of driver's field of view
- indication of concealed objects

Contact-analog vs. unregistered

With AR technology virtual objects can be rendered in close proximity to relevant objects in the environment. Opposite to available on-board displays, AR schemes can be placed at or near the location where the necessity for the information exists. Definition of contact-analog presentation is denoting the definition of AR even further: it is not sufficient that the information is presented interactively in the 3D world in real-time but it has to be correctly aligned (even in focal depth) and it has to have a tight connection to the physical space.

Contact-analog presentation schemes do not require the driver to perform spatial calculations and should therefore enhance information perception and reaction times better than unregistered presentations. Such schemes have the potential

to considerably increase rapid information recognition and to decrease a drivers' cognitive workload while performing some tasks. The primary advantage is that such presentations are compatible with gained inner models and require no mental effort for transcription of spatial transformations between the information and the location of concern.

Considering the complexity of the new technology, it is important to determine to what extent this happens and in which situations the advantages of contact-analog displays are valuable enough to justify their application and in which situations the presentation of 2D unregistered symbols suffice.

Visualizing occluded objects

Upcoming sensor and tracking technology and new ways of communication such as Car2Car and Car2Infrastructure will enable full survey of the environment and correct determination of the position and motion of other traffic participants. Therefore, subsequent positions of possible hazards and the desired position of virtual informative objects can be calculated and intergrated into the real environment. In that way, even a position of occluded hazard objects can be revealed to the driver.

Beyond technical challenges such as tracking and correct registration, an additional challenge in AR is the design of adequate user interface. The visualization has to be accomplished so that it conveys abstract information in an intuitive way. One of the topics highly relevant to AR in medicine or military is the visualization of occluded objects (Livingston et al., 2004), (Wimmer et al., 2008).

The intuitive presentation of occluded objects is a complex problem. Human experience gained during epitaxial growth generates cognitive limitations for the understanding of spatial relationships in combination with occlusion. Occlusion is the primary cue in perception of information (Cutting, 1997). When we depict occluded objects with an AR metaphor this cue is diminished and the perceived image does not correspond to the user's mental understanding of properties of the real world. Therefore, a key problem to solve is to find a way to depict occluded objects in such a way that the human can correctly understand its distance and the spatial relationships between the physical and the virtual object.

It is an important question which cues to use when showing virtual representations of objects integrated into a real scene. In a study conducted by Livingston et al. (2003) users misjudged occlusion relationships in about 10% of all the trials, even when the best graphical presentation was used. In time-critical environments, presenting occluded information in an intuitive way is even more complicated.

There are different approaches for this problem in the field of AR like *Ghost*, *Cutaway*, *Explosion* presentation or their combination (see Figure 7(a)). An approach worth mentioning, eventhough 2D, is the *Halo technique* (Baudisch, 2003). It is a method for viewing large area on small screens. An example is shown on Figure 7(b). The PDA screen shows five arcs which indicate locations that lie outside the display area of the screen. However, the arcs convey all information required to identify locations. The higher the curvature of the arc, the closer is the referenced location.

Presentation of occluded objects in the automotive industry was introduced by Taya et al. (2005). He suggests a virtual slope to reveal occluded vehicles in the opposite lane of an intersection (see Figure 8(a)). The view is augmented using cameras that are mounted at traffic lights. An approach comparable to the virtual slope was presented by Kojima et al. (2005) (see Figure 8(b)). They show the drivers' blind spot in a so called virtual mirror.



(a) Ex example of *Ghost* and *Explosion* techniques (Wimmer et al., 2008)

(b) *Halo* visualization technique on the example of navigation information on PDA

Figure 7. Different AR visualization techniques for occluded objects



(a) Virtual slope revealing occluded objects in the opposite lane of intersection (Taya et al., 2005)

(b) Mirror view augmenting the drivers' view with information from the blind spot area (Kojima et al., 2005)

Figure 8. Driving assistance systems concepts presenting the visually concealed objects

Form of presentations for occluded objects

As already argued, it is justified to individually explore the best form of presentation for different types of objects indication: within and outside driver's field of view and indication of concealed objects.

Bergmeier and Lange (2008) analyzed the best presentation type for direct indication for a Night Vision System. He has shown that contact-analog presentation outperforms spatially unregistered presentations when indicating hazards in the driver's field of view (see Figure 5(b)).

Tönnis and Klinker (2006) analyzed the best frame of reference for guidance of a driver's attention. They compared a contact-analog visualization of the direction of a danger (see Figure 9(a)) with a spatially unregistered one (see Figure 9(b)). The results have shown that the contact-analog indication, using a 3D arrow mounted on a pole at the front bumper pointing to the dangerous location resulted in a faster reaction time than the unregistered bird's eye view presentation.



(a) Contact-analog presentation

(b) Symbolic unregistered visualization

Figure 9. AR symbols for guidance to the imminent danger (Tönnis & Klinker, 2006)

The question of the best frame of reference for indication

of occluded hazard objects is still a topic of investigation. A major goal of the study reported in this article is the investigation of a suitable frame of reference for referencing occluded objects.

APPROACH AND THE GOAL

The section presents approach used for the investigation of AR presentations and determination of the best way to present visually concealed hazards.

For accurate evaluation of safety visualizations, testing in realistic environments is essential. The driver should be exposed to similar conditions and strained with a comparable workload as he would have in a safety critical situation. Evaluating the same presentations on paper or from videos could falsify the results. Therefore, special attention was paid to careful design of traffic scenarios in which the developed AR schemes are to be tested. Up to recently, simulation of critical traffic situations was not feasible due to inadequacy of existing software to simulate such situations realistically enough. However in the fixed-base driving simulator of the Institute of Ergonomics, TUM, realistic critical traffic scenarios could be created.

Method

The method applied represents an iterative process of designing different AR-based concept for concealed objects and testing them in the driving simulator environment (see Figure 10). To define the most appropriate scenarios, we applied a task analysis on different traffic scenarios. In parallel, the potential of AR-based presentation for these scenarios was estimated. The urban intersection scenarios revealed to be promising for AR-based applications. Intersections finally were chosen because of their high probability for occlusion of relevant objects. Visibility issues can complicate perception of relevant traffic participants, being a major cause of accidents. In addition, high accident counts at intersections (around 35%) requires more analysis to explain likely reasons. Thus, four critical intersection scenarios were designed and implemented in the static driving simulator.

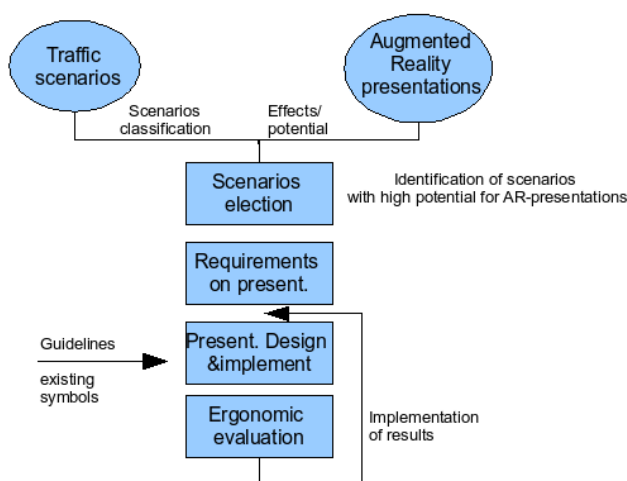


Figure 10. Iterative design of AR-based presentations for ADAS

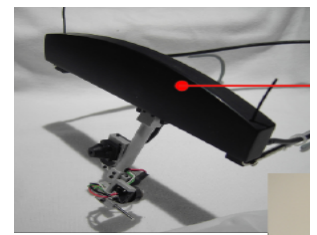
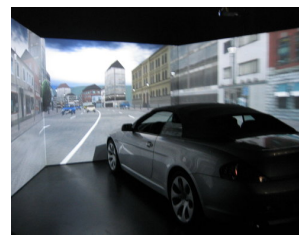
The next step was the conduction of a pilot study in which the intersection scenarios were tested for their severity and realism. It was also evaluated in which scenarios the test drivers would request support and how the design of selected warnings was perceived. Development of AR presentation schemes require fresh input and new ideas. More flexible approaches are desirable than is the case with prevailing symbols. Therefore, pilot study served to collect these ideas,

independent of the frame of reference and contact-analog and unregistered presentations. (Green, 1995) performed some experiments in which existing traffic symbols were not the most preferable ones. In his experiments he showed that the preferred warning format (text or graphics) varied from warning to warning.

There are two general methods when designing warnings: self-creation and creation by integrating subjects. The combination of both methods gives the best results, therefore several state-of-the art and several self-designed concept-drafts were chosen for evaluation and discussion with the subjects. Based on the results and input obtained from the pilot study, new warning visualizations were developed in the third step. These presentations were then merged realistically into the driving simulation environment and tested for acceptance and usability in a final study.

Experimental Environment

The fixed-base driving simulator used in the conducted study is presented in Figure 11(a). The simulation software provides a flexible framework for the implementation of different scenarios and for controlling other vehicles and pedestrians as well as fine-grained control over the look and feel of the environment (SILAB, 2009).



(a) Fixed-base driving simulator of the Chair of Ergonomics, TUM

(b) Eye tracking system: Dikablis (digital wireless gaze tracking system)

Figure 11. Experimental hardware used for the pilot study

The eye-tracking system Dikablis (digital wireless gaze tracking system) was used to register eye movements. It is a light-weight head-mounted eye tracking system developed at the Institute of Ergonomics, TUM (see Figure 11(b)). With an available graphical user interface, the system can be calibrated and the data can be analyzed both manually and automatically (Lange et al., 2005).

PILOT STUDY

This section presents the experimental course, the procedure, test samples, results of the pilot study and the selection of the presentations for further evaluations.

Experimental Course, Procedure and Test Sample

The experimental course was divided in two urban environments, consisting of ten intersections each. Four of them represented critical situations and in three of them the driver had an obstructed view. The road course is described in detail in (Plavsic et al., 2009).

After finishing a drive through the test-track, test subjects were again seated in the vehicle and different visualization strategies were presented on the projection wall. Screenshots of each of the four critical scenarios were augmented with different warning presentations and shown for discussion. From each intersection, two screenshots were made, one about 5 seconds before entering the intersection and one shortly before the critical situation occurred. Subjects were asked to rank different concepts and to decide when they would prefer

a warning. Before seeing the concepts, subjects were asked to express what kind of help they would like to have in a particular situation.

The primary sample involved 30 subjects, mainly students from the Technische Universität München. One third did not finish the test due to simulator sickness. The analyzable subject sample ranged from 21 to 54 years ($\mu = 25.8$, $SD = 7.27$).

Symbols for Evaluation

Altogether nine different concepts in 36 different constellations were discussed, some of them being self-designed and some consisting of existent symbols. Self-designed warnings were developed on the base of already existent symbols in traffic, augmented and virtual reality, aero-traffic and computer games. A brief explanation of each of them is follows:

- 2D unregistered warning icon in two color variants showing a sketch of the own car and the potential danger. This symbol was best graded within the scope of Julian (2005)
- 2D continuous unregistered icon developed by the Intersafe (2005) project
 - 2D contact-analog symbols in three variants:
 - Contact-analog variant of intersafe symbol: navigation arrow indicating both the drive path and estimated situational risk level
 - Navigation arrow with estimated situational risk level and additional indication of the hazard's direction
 - Adapted drive path indicating direction of hazard
 - four 3D contact-analog symbols:
 - 3D arrow as one of the simplest and the most common symbols used in AR for guidance of visual attention
 - 3D arrow with a symbol indicating the type of the hazard
 - AR highlighting symbol in the form of a *Bounding box*
 - *Glow*: AR symbol presenting a similar concept as *Bounding box* but more intensively

Results

The results indicate that drivers require support more for situations with sight obstruction and vulnerable traffic participants than the assistance with the complex driving tasks. The subjective wish for synthetic AR information was low.

Concepts using some kind of arrow were overall evaluated best, followed by the 2D symbol developed as a part of Julian (2005) (see Figure 12(b)). As the most appealing and intuitive symbol, contact-analog arrows with a pictogram was selected. Drivers expressed a tendency for discrete and earlier warnings.

Selected Warning Visualization Schemes

Based on the results of the pilot study, four different visualizations (see Figure 12) have been selected for further analysis. Two presentations are exemplary representatives of unregistered exocentric 2D icons and the other two of 3D contact-analog schemes. The four visualization schemes were implemented in the two selected most demanding intersection scenarios.

When designing these symbols, standards and guidelines were followed. Thus, these symbols have an orange color. Also, as the acceptance of the visualization schemes and concepts depends extremely on the design of the icons, we tried to present all concepts to be visually equally appealing and on the same development level - as simple as possible and without any fancy effects. The chosen symbols present the simplest representatives of each of the categories.

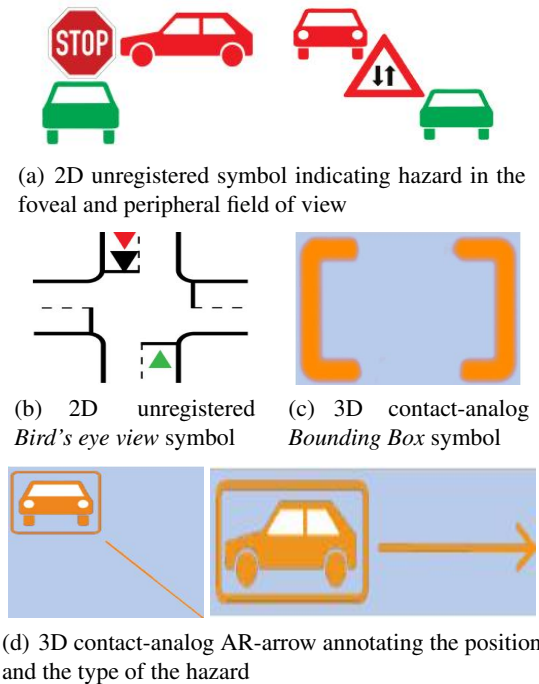


Figure 12. Warning symbols chosen for further evaluation in the main study

The 2D unregistered traffic symbol is the only symbol taken directly from the pilot study. Two different variants of this symbol were implemented according to the actual traffic situation in the scenario, as shown in the Figure 12(a).

The 2D unregistered *Bird's eye view* symbol shows a virtual sketch of the intersection from a bird's eye view with the cars in the vicinity and highlighted potential dangers (Figure 12(b)). For reasons of simplicity, just the necessary information is depicted on the map. Vehicles are simplified and presented as triangles.

The 3D contact-analog annotating symbol presents an arrow pointing to the potential hazard in conjunction with a symbolic icon informing the driver about the type of the hazard. Two slightly different versions have been implemented (Figure 12(c)): according to the actual traffic situation in the scenario.

The 3D contact-analog *Bounding Box* symbol presents animated variant of a *Bounding Box*: a bracket-like object floating around the potential hazard (Figure 12(d)).

The contact-analog symbols were merged into the simulation such that the visualization appeared as a part of the environment. Unregistered symbols were included into the simulation like normal HUD icons on the location where available HUDs have their presentation area. All strategies were presented to the driver at the same moment, which is about 5 seconds before the potential collision occurs. Implementations of the warning strategies in the driving scene are shown in Figure 13.

MAIN STUDY

This section covers the presentation of the experimental course, the procedure, the test sample and the results of the main study.

Experimental Course, Procedure and Test Sample

The course consisted of 16 intersections of interest, eight being cross-intersections with the occluded objects coming from the front and eight being T-intersections with occluded

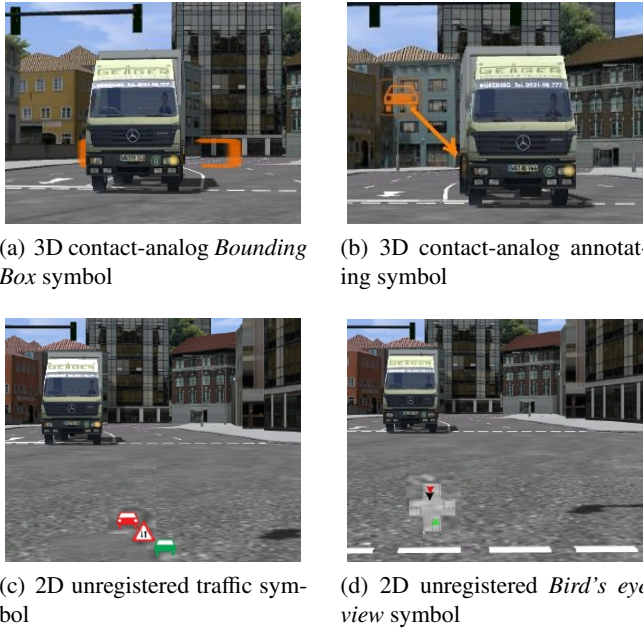


Figure 13. Chosen warnings implemented into the Scenario 1

hazard vehicles appearing from the right. To reduce learning effects, two visually different versions of each of the scenarios were implemented. In addition, two intersections with the same scenario but no hazard vehicle were added to each course. Therefore, each subject drove seven times through each individual intersection, once in a baseline, four times for each peculiar presentation and twice without a hazard vehicles. It took about 16 minutes on average to drive through the whole test course.

To avoid experimental bias, the AR presentations were permuted. The experimental design plan is shown in Figure 14. Each of the four different modules presents a sequence of different intersections and warning strategies. These four modules were permuted in 24 different ways, so that each participant experienced an individual design.

Modul 1	S1-0	S2	S1-M	S2-M
Modul 2	S1-M	S2-0	S1	S2-M
Modul 3	S1-M0	S1	S2-M	S2-0
Modul 4	S1-M	S2	S2-M0	S1-0

S1	Scenario 1 with no hazard objects
S1-0	Scenario 1 with no hazard objects
S1-M	Visually modified scenario 1
S2	Scenario 2
S2-0	Scenario 2 with no hazard objects
S2-M	Visually modified scenario 2

Figure 14. Experimental design plan, each subject was driving through different module sequence

Participants firstly familiarized themselves with the driving simulator environment. They filled out the demographic questionnaire. Subsequently, they were equipped with the glance tracking system Dikablis and drove the experimental trial. They were instructed to drive as they normally would and to obey traffic regulations.

Each warning concept appeared twice in direct subsequence. After presenting the second one, the test drive was

interrupted and the participants were given a questionnaire to evaluate the warning. Questionnaires were comprised from:

- NASA Task Load Index (NASA TLX) questionnaires for assessing the overall workload (NASA, 1988)
- Likert scale for assessing intuitiveness, decision making, feeling of safety and distraction
- Redundant ranking questions referring to attractiveness, intuitiveness, concentration and safety
- Semantic differential questionnaires with following categories: practical, motivating, confusing, attractive, comfortable

In addition, open questions referring to the general design, its position, the size and the desired time of the warnings were given and the answers were collected.

The analyzable subject sample ranged from 19 to 29 years ($\mu = 23,68$, $SD = 2,84$), four of them being females.

Results

For the statistical analysis a significance level of $\alpha=0.05$ is defined. On the figures, the significance is depicted by arrows.

NASA TLX. The NASA TLX is a multi-dimensional rating procedure applied for assessing the Overall Workload Index (OWI). It consists of six subscales: mental, physical, temporal demands, own performance, effort and frustration. Based on a weighted average of all ratings, an overall workload score can be determined. The higher the value the higher is the subjective workload.

An one-way repeated measures, ANOVA showed a significant difference in OWI between baseline and assistance support ($F(4,92)=5,074$, $p=0.001$, see Figure 15). However, there was no statistically significant difference between different kinds of assistance. The tendency for the lowest workload reside with *Bird's eye view* and *3D annotating symbol*.

Concerning particular dimensions aspects, the *3D annotating symbol* performed best, however with no statistically significant difference to the other concepts. Statistically significant was the dimension of 'Performance' in which post-hoc t-tests showed the difference between the *Bird's eye view* and the *3D Bounding Box* ($t(23)=-2,415$, $p=0.024$) and between the *3D Bounding Box* and the *3D annotating symbol* ($t(23)=-3,203$, $p=0.004$) (see Figure 16 and 17).

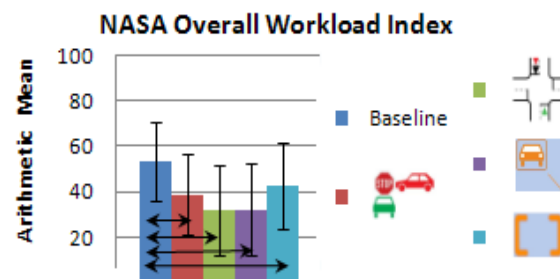


Figure 15. NASA Overall Workload Index (OWI) between baseline and four different concepts

General Evaluation. The general evaluation of assistance support was assessed by two 5-point Likert questions evaluating whether assistance system increased the subjective feeling of safety, and whether the assistance system caused additional distraction. The assistances were evaluated as increasing safety ($\mu = 3.88$, $SD = 0.97$) and not bringing too much distraction ($\mu = 2.4$, $SD = 0.93$).

All assistance had no significant difference in enhancing the understanding of the situation, except for *3D Bounding*

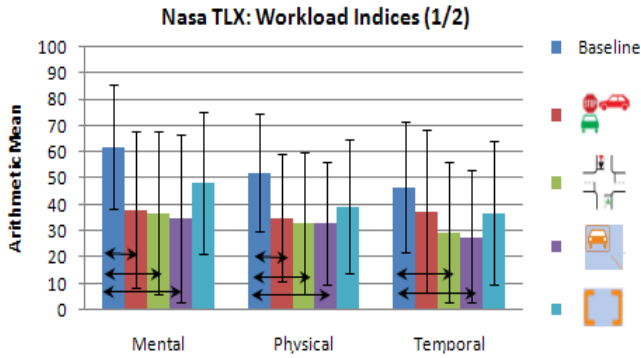


Figure 16. Mental, physical and temporal demands dimensions of NASA TLX questionnaires

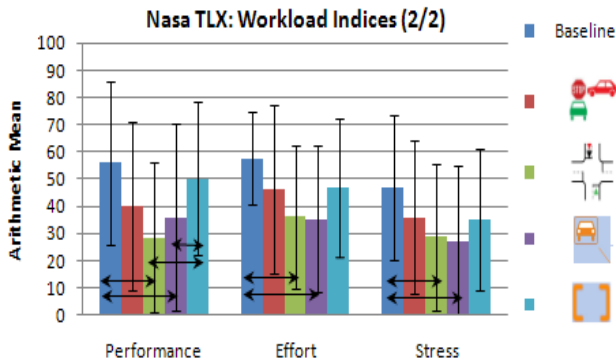


Figure 17. Own performance, effort and frustration dimensions of NASA TLX questionnaires

Box which was evaluated significantly worse than the other schemes (Figure 18).

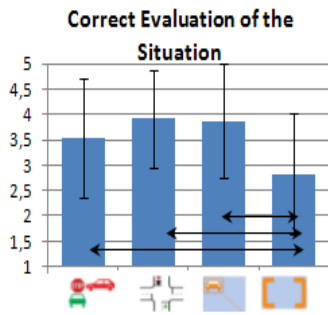
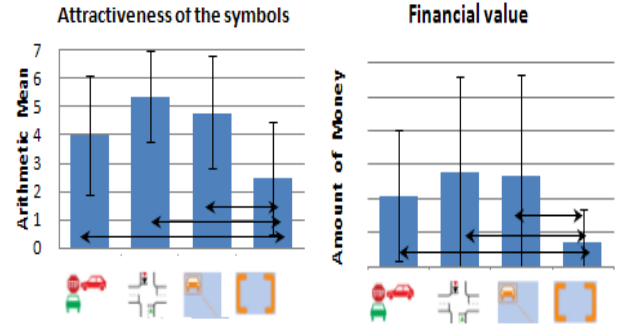


Figure 18. Subjective evaluation whether particular presentation support correct evaluation of the situation

The attractiveness of the symbols had similar results. The *Bird's eye view* and *3D annotating symbol* were considered most attractive, yet without significance. The *3D Bounding Box* was again evaluated as significantly the least attractive symbol (Figure 19(a)). This was reflected in the readiness to pay for presented assistance (Figure 19(b)).

Semantic Differential. The semantic differential showed the similar tendencies: the *Bird's eye view* and the *3D annotating symbol* were evaluated as being more practical, motivating, clear, attractive and comfortable than the other two presentations (Figure 20).

Ranking. As the last task in the questionnaire, participants had to sort all four presentation types and baseline from 1 (worst) to 5 (best) with regard to intuitiveness, concentration, safety feeling and attractiveness. Friedman's two-way test showed significant differences in all



(a) Attractiveness of particular presentations (b) 'How much money are you ready to pay for particular assistance?'

Figure 19. Attractiveness of tested concepts

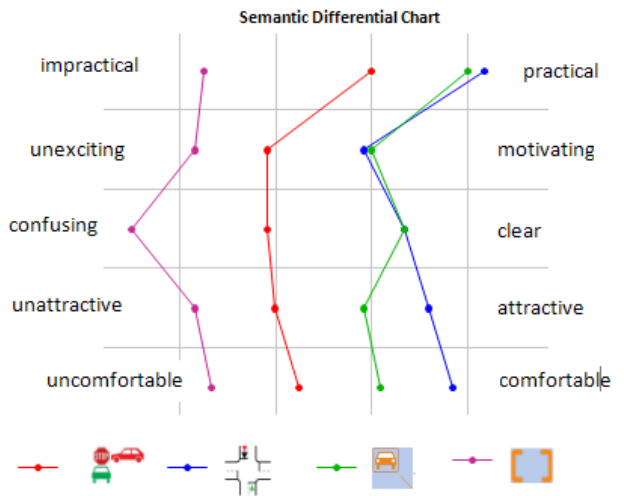


Figure 20. Semantic differential of tested concepts

the categories: intuitiveness ($\chi^2(4)=9.467, p=0.05$), concentration enhancement ($\chi^2(4)=15.891, p=0.003$), feeling of safety ($\chi^2(4)=18.770, p < 0.05$) and attractiveness ($\chi^2(4)=9.467, p < 0.05$).

The post-hoc Wilcoxon test showed significant differences with respect to intuitiveness. The *3D Bounding Box* did significantly worse than both, the *Bird's eye view* ($Z=-2.723, p=0.006$) and the *3D annotating symbol* ($Z=-1.965, p=0.049$). The *3D Bounding Box* was also ranked significantly worse than the *Bird's eye view* regarding the aspect of concentration ($Z=-2.653, p=0.008$). For the aspects of safety, there was a difference between the *Bird's eye view* and the *2D traffic symbol* ($Z=-2.183, p=0.029$) and between the *Bird's eye view* and the *3D Bounding Box* ($Z=-3.084, p=0.002$).

Number of Accidents. The number of accidents which were caused in spite of the assistance of a particular warning symbol is objective measurement of the effectivity. The results are in compliance with subjective measurements (Figure 22). The number of accidents caused when using *3D Bounding Box* was surprisingly high. Especially curious is the number of accidents which were caused when the symbol was presented for the second time. With the *Bird's eye view* just one such accident occurred and with the *3D Bounding Box* ten.

DISCUSSION

In summary, the *Bird's eye view* concept outperformed all other schemes, followed by the *3D annotating symbol* in almost all usability aspects. The results show that the men-

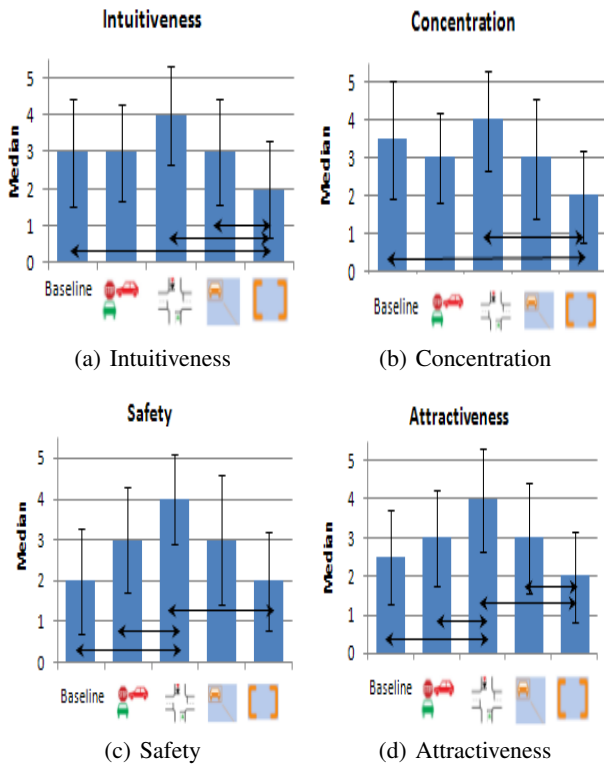


Figure 21. Ranking of tested concepts

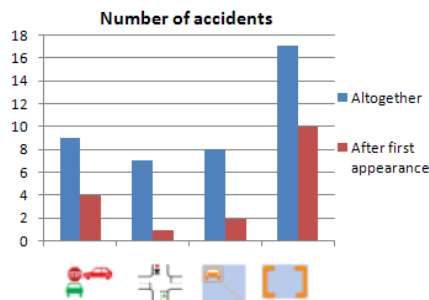


Figure 22. Number of accidents caused with a particular presentation type altogether and when the symbol appeared for the second time

tal workload was significantly decreased with all presentation schemes, this being mainly the consequence of reducing time-pressure from the detection task.

Ergonomic rules of compatibility are prompting driver's point of view for the driving task and especially for local guidance. This is at least the case for the indication of visible hazards. For invisible objects, it is reasonable to expect that a contact-analog presentations exceed unregistered symbols, in particular the *3D Bounding Box* scheme. The argument for better acceptance of the *3D Bounding Box* symbol over the *3D annotating symbol* is its expected intuitiveness. With the arrow, there is one mental transformation necessary to determine the position of the hazard. However, this was not the case. Both subjective and objective measures reside on the side of the exocentric presentation, followed by the 'guidance' presentation.

It was also surprising that so many accidents happened with the *3D Bounding Box*, even after the symbol was already shown in the very same scenario. It indicates that subjects had no understanding of the meaning of this symbol. The positive observation of this is that there was a very low learning effect of critical scenarios even though the same scenario appeared 5 times during the test run.

Type of reference	Suggested AR presentation's type
indication of objects within driver's field of view	contact-analog, egocentric
indication of objects outside of driver's field of view	contact-analog, egocentric
indication of concealed objects	exocentric

Figure 23. Suggested forms of AR-presentations for different types of reference with regard to *Frame of reference* and *Representation type*

Nonetheless, if we take already discussed human perception of depth and occluded objects into account, these results are not that unforeseeable. Humans have problems disposing the egocentric virtual image of a concealed objects in the real world and understanding spatial relationships correctly. An appropriate mental model are supported better by the exocentric point of view. This finding corresponds to studies conducted by Wither and Höllerer (2005) and Livingston et al. (2003). In these studies, the top-down view also came out as the preferred technique to provide distance information to the user, both in the questionnaire and with respect to accuracy.

It can be concluded that when the augmented object resides in the driver's field of view, AR has potential for being applied in vehicles. When the situation is occluded for the driver, it is preferable to have full understanding of the situation by having the own position augmented. Such presentations, with a user presented by an avatar are called tethered presentation and they appear to be the best solution for indication of occluded objects (see Figure 23).

However, the AR scheme in the form of arrow-based annotation, as a symbol between 'egocentric' and 'exocentric' presentation was evaluated rather well. Therefore, variations of this symbol should be investigated further. The additional advantage of the *3D annotating symbol* is that with this form of presentation it is possible to steer the attention of the driver, for example from his actual forward view to a side. This is actually beneficial if we keep the size of the HUD in mind.

The presentation of occluded objects can lead to information overload and to the so called „Superman's X-Ray Vision“ problem. A possible solution can be interactive techniques. Some of them are already developed in the other fields. For example, Bane and Höllerer (2004) presented a view-management component that addresses dynamically changing visibility relationships among moving objects, and applied it to 3D user interfaces. However, this is a disputable solution for time-critical environments.

One more comment concerns the *2D traffic symbol*. Eventhough it was chosen as the best evaluated symbolic icon in the pilot study and in (Julian, 2005), there is an eliminating argument for this symbol. The color choice can confuse the driver in a sense that he can understand the green color as a permission to drive further in critical moments. Eventhough the majority of the drivers interpreted the colors correctly, it suffices that one driver gets confused with the colors. Thus this scheme cannot be ranked as the best in spite of the best mean or median value.

CONCLUSION

This paper gives an overview of AR applications in automotive area and discusses the potential of AR presentation

schemes for indicating visually concealed hazards. The examined aspect concerning this question is which frame of reference helps the driver to assess the situation with occlusion objects the best.

The results show unambiguously that the most preferable schemes for showing occluded objects are schemes giving an overview of the whole situation, followed by contact-analog annotation symbol of the hazard. In addition, enhancement of the situation is improved even more with a tethered presentation, a presentation depicting an avatar of the own vehicle.

Eventhough, the analysis was done with relatively generic symbols, before coming to a final conclusion, further tests are necessary, in particular to investigate dynamic characteristics of AR-schemes. The current experiment has also tested the intuitiveness and understanding of concepts introduced to the driver for the first time. Possible reasons for these results can reside in the drivers' established routine in the application of symbolic warnings. Therefore it can be beneficial to evaluate if the learning adaptation can improve the understanding of such concepts.

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