

Survey and Classification of Head-Up Display Presentation Principles

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With increasing size of Head-Up Displays and sensor technology Augmented Reality gains the potential to be used in automotive environments. Head-Up Displays provide a third dimension for information presentation. The increased dimensionality and the fact that the display space contains the outside environment which is essential for safe driving generates new opportunities for information presentation but also new issues. This paper collects the common principles for information presentation in the Head-Up Display and classifies these in according dimensions. Pair-wise combinations of the classes are used to illustrate examples for presentation concepts. Awareness about the different concepts and their underlying principles enables avoiding potential cross-relationships between multiple dimensions and thus enables unique attributing of effects in user studies.

INTRODUCTION

The automotive Head-Up Display (HUD) technology provides the advantages of keeping the eyes near the road and of minimized focal re-accommodation time. Such display technology offers various opportunities for different types of information presentation. Information in regularly available HUDs is shown in symbolic style, but emerging contact-analog HUD technology, allows for a wider range of information presentation: virtual 3D information can be interactively superimposed in the driving environment through Augmented Reality (AR).

To ecologically design and experimentally evaluate such presentation schemes for different driving situations, several more dimensions emerge that are relevant in comparison to conventional presentation. To take into account all aspects of a presentation for a certain application, a careful classification of presentations must be at hand during the development process to weigh their effectiveness. All options thus can be considered and the best can be chosen for implementation and examination.

In consequence, it is necessary to develop experimental methods for testing and evaluating these presentations in the automotive environment. To accurately evaluate different presentations against each other, experimental bias of chance variables has to be eliminated. All different aspects and dimensions have to be isolated and carefully distinguished from each other.

Appropriate classification methods are missing not just in automotive applications, but in designing and evaluating AR schemes in general. This paper contributes a survey of presentation principles in emerging contact-analog Head-Up Displays with respect to the following classes of dimensions: (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. The first class differentiates between continuous information, e.g., like a speedometer, and discrete events like warnings. The second class spans the continuum between 2D and 3D information presentation, covering intermediate presentation styles like 2.5D. The third class distinguishes whether information schemes are registered and aligned with the 3D environment or show unregistered content. The fourth class covers the frame of reference of the user pertaining to the presentation of the information. The fifth class concerns

the environmental situation and analyzes if an object or a situation is directly visible, occluded in the field of view or if it lies outside the driver's field of view. The sixth class deals with mounting information relative to the driver's glance behavior.

Each of these classes is introduced in detail. The corresponding dimensions are investigated. The collection of the different classes provides a checklist to categorize already developed presentation schemes and enables derivation of further alternatives. In addition, cross-relationships between elements of different dimensions are illustrated, showing where changes in presentation style affect multiple dimensions. Such multiple influences complicate statistical analysis and prohibit determination of separate causes for effects. Knowledge about these cross-relationships instead enables the design of usability studies where only one independent factor can be changed at a time.

3D SPACE FOR INFORMATION PRESENTATION

Augmented Reality (AR) extends the three-dimensional world by superimposing computer-generated virtual objects into the environment of the user (Azuma, 1997). Information furthermore no longer requires stationary displays as carrier, but can move into the world. Spatially embedded virtual objects can contain and transfer information about associated real objects, places or events.

With the AR paradigm, information has the potential to be presented at the place where the cause for the need of information presentation is located. Thus the number of glances to in-car displays can be reduced. The combination of objects or places and their inherent information allows for condensed information and thus for enhanced perception. The presentation of information changes and uses new, implicit presentation schemes that require less mental load for interpretation. Especially information related to the spatial relationships in the environment of the car has the capability to be transferred to AR. AR thus has the potential to become a notion for the incorporation of driver and safety related information into the automotive domain.

Since conventional displays can present information only on a 2D surface, AR extends the dimensionality and enables information presentation in three dimensions. The extension to three dimensions generates new ways for information pre-

sensation but also generates issues for the determination of the best concept realization. The available 3D space is not explored to the extend the 2D presentation space is explored for suitability of presentation. Two main issues arise for this space: the surrounding of the user already has content and information now can be presented at different distances.

The first issue, existing content in the presentation space, requires new strategies for information placement. Two main reasons apply here. First, AR schemes appearing to be locally fixed in the environment move over the HUD when the car is in motion. This effect reveals because the location where the scheme is to be shown moves over the windshield. The AR scheme thus has to move accordingly on the HUD so that it appears as standing still in its position in the environment. The second reason why new placement strategies are required concerns issues of dynamic layouting to avoid occlusion of objects of relevance. The presentation space itself contains objects and areas of relevance for the driving task, such as the participants in traffic or road markings. No relevant information from the environment must be occluded. AR objects can employ dynamic layouting strategies such as the strategies of Bell, Feiner, and Höllerer (2001) for view management. Virtual objects can float in the neighborhood of other objects in the surrounding without occlusion. Both cases generate effects of indirect movement of objects. No absolute fix-point is available anymore, only relative fixations exist.

The second issue has its foundation in technical properties of displays and 3D computer graphics. Conventional 2D Displays show 2D information without depth on a 2D display. The information is perceived from the display. The human eye accommodates to the distance of the display and captures the information shown. AR Displays in general place a virtual 2D image plane in the space in front of the view of the user. A 2D image plane is sufficient because the display is spatially decoupled from the perceived image. Here the image plane is an invisible area where information can be shown. This image plane has a certain distance to the user, the focal distance. The human eyes accommodate to that distance to capture the image. 3D presentation schemes shown on that display in contrast can have any distance to the user. The distance of the virtual object is a perspective transformation. The computer generated object is rendered on the display according to the field of view of the viewer relative to the display. Both distances, the focal distance and the perspective distance, differ in most cases except an object is rendered at equal distance. Fig. 1 illustrates the relationship of both distances in a sketch. Presentation of AR schemes for automotive applications requires changing distances when the car is moving.

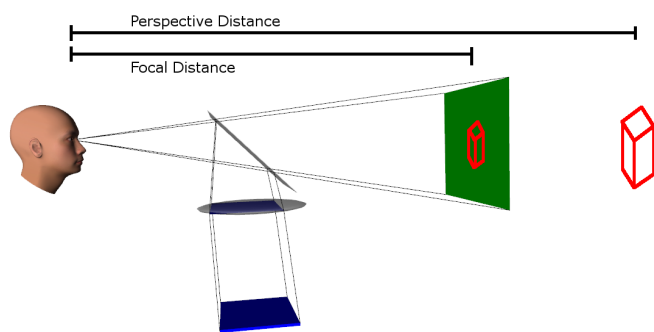


Figure 1. Sketch of a HUD showing different Focal and Perspective Distances: a Display (bottom, blue) and a Lens (above Display, grey) placed in a Setup that the Image combined by the Windshield (tilted, above Lens) appears in a specific Focal Distance (vertical green plane to the right). The 3D Shape (red cube) is rendered in a larger Perspective Distance

Both issues for the design space of AR presentation, the indirect movement of virtual objects and the differing distances generate confounding factors for user studies. The design of AR schemes whether it is a pure transfer of a conventional displays to a HUD or an implementation of a new metaphor incorporates the mentioned effects. To conduct user studies with results uniquely attributable to single modifications, all possible compounds and cross-relationships must be at hand to keep the bias low.

CLASSES OF DIMENSIONS FOR INFORMATION PRESENTATION

Several user studies concerning the use of AR for advanced driver assistance systems have been conducted over the last years. The experiments of Plavšić, Duschl, Tönnis, Bubb, and Klinker (2009), Tönnis, Klein, and Klinker (2008), Tönnis, Lange, and Klinker (2007) and Tönnis and Klinker (2006) covered a broad spectrum of automotive AR systems.

The concepts that are used in these experiments were analyzed concerning their principles. This analyses lead to a collection of classes of principles for information presentation. This section illustrates all classes of principles and investigates their dimensions.

Continuous vs. Discrete Information Presentation

The first class differentiates between continuous and discrete information. It will be referred to as *Continuity* in subsequence. Continuous information in general is status data like it is given by the speedometer. Such data must be unobtrusive or ambient, it otherwise would capture too much visual space or cognitive load of the driver. Discrete information in contrast is information given to the user on a specific event. An example for discrete information is a navigation hint at a certain waypoint. Warnings are also classified to discrete information. Such data must use immersive cues to get noticed by the driver.

Especially discrete events are of concern in the automotive environment. Such event interrupt the control cycle of the driving task (Bubb, 1993). The driver has to draw his attention unexpectedly to another input source and therefore is taken out of the control cycle. Perception of continuous information also takes the driver out of the control circuit, but such an action can be timely planned, because the information is continuously available.

Especially the introduction of the HUD and the possible future AR-capable HUD bear the potential to port some systems that currently use discrete events to an ambient continuous visualization. Such visualization then increases the situational awareness and probably reduces the number of events where a driver has to immediately react on a certain event. Through this, concepts undergo a deep shift in their general paradigm. The use of other presentation principles then has to reflect this to enable according analysis of different concepts.

2D Symbolic vs. 3D Information Presentation

The second class spans the continuum between 2D and 3D information presentation, covering intermediate presentation styles like 2.5D. A 2.5D presentation is a 2D shape that is stretched in depth. It will be referred to as *Representation* in subsequence. While presentation schemes on conventional displays in general are two-dimensional, it also can generate an impression of 3D. Such impressions are reached, for instance, in menus by use of shadow effects or in drawings by perspective views.

AR displays, such as HUDs, which decouple the display from the image plane increase perception of 3D in comparison to conventional displays. 3D virtual objects rendered perspectively are better perceived as having a spatial shape. HUDs feature the presentation of 3D objects but also allow presenting information in 2D. The HUD which is available on the market is such a display. It, e.g., shows the speed or symbolic navigation information. Intermediate presentation styles, such as 2.5D are possible. The representation of depth can also be reached by a visual prolongation of a 2D shape.

Contact-analog vs. Unregistered Presentation

The third class distinguishes whether information schemes are registered and aligned with the 3D environment or show spatially unregistered content. The term *Registration in Space* will be used in subsequent to refer to this class. Contact-analog AR is an extension to the paradigm of AR (Tönnis, 2008). Besides interactive integration of registered virtual 3D content into reality, further constraints are required to reach contact-analog AR. Presentation in AR can be classified between *symbolic* and *naturalistic* presentation. Symbolic presentation embeds abstract symbols. Naturalistic objects in contrast are objects that look realistic and behave like real objects. Contact-analog AR has a strong dependency to realistic and naturalistic presentation. The computer generated objects reflect the physical state and behavior of the environment. AR schemes smoothly integrate into the environment. Contact-analog AR requires a correctly calibrated and spatially registered display so that the presented AR schemes appear to behave like real objects. If a HUD is not calibrated accordingly, the object seems to behave differently and moves or distorts according to the placement on the HUD. While an AR presentation never should be distorted, correct registration might not be necessary in some cases. Abstract or symbolic content does not necessarily have to be registered accordingly. Information of that kind can be placed at differing locations and can even be placed in a different depth. Presentation although should ensure that depth cues are not inversed. Presenting an object in a distance larger than the distance to the background object can generate obfuscation. The user knows that the one object should occlude the other object but the object is visible. Does that tell the user that he thinks wrong and the object is really in the front of the other or can he handle that x-ray-like effect?

The potential difference between focal and perspective distance has its impact here. If the virtual object, for instance, is presented in a way that its focal distance is larger than its perspective distance and the virtual object occludes a real which is nearer than the focal distance, the effect of irritation can be even higher. Fig. 2 explains this in a sketch. The human eye focuses to the distance of the virtual image plane, the focal distance. The image rendered there is presented in the properties of a much shorter perspective distance. A real object, in this example a car is nearer than the focal plane. The user has a reversed depth cue. While his eyes have to focus on a large distance to perceive the image does he realize that this image occludes a nearer object.

Such effects can occur if a HUD has a fix focal plane in a larger distance. When, as in our example, a navigation arrow is shown which already is near to the own car, its perspective distance is much shorter than the focal distance. Any real object in between, for instance, a car crossing an intersection now generates this occurrence.

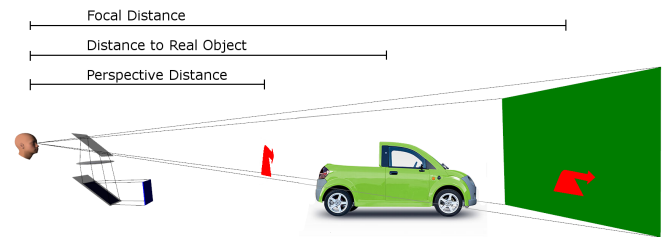


Figure 2. Sketch illustrating ambiguous Depth Cues: The Human Eye focuses to the Focal Distance to perceive an Image. The Image is rendered in a Perspective Distance shorter than a real Object (green car). The user has a reversed Depth Cue

Presentation in Different Frames of Reference

The fourth class covers the *Frame of Reference* of the user pertaining to the presentation of the information (Tönnis, 2008).

Egocentric and Exocentric Presentation. Information presentation in the field of computer graphics is classified according to a *continuum delimited by egocentric and exocentric* information presentation. The egocentric end is defined by the classic idea of AR. Information is fully embedded in the user's personal frame of reference and shown from the user's own point of view. 3D information thus is seamlessly embedded into the surrounding world. The exocentric end of the continuum is defined by information presented from a completely different frame of reference. Usually this different frame of reference is rigidly mounted to the world surrounding the user. In between these two boundaries, information presentation varies depending on the number of degrees of freedom altered. Objects and viewpoints have six degrees of freedom, three translational and three rotational. The localization in the continuum changes depending on the number of degrees of freedom altered. Starting at the egocentric end of the continuum, all six degrees of freedom between the user's point of view and the point of view of the AR system correspond to each other. The translational degrees of freedom can be assumed to be located closer to the egocentric end of the continuum, because translations are easier to deal with than rotations. Moving the point of view of the AR system along one translational axis is the first step away from the egocentric end. The viewing direction remains unchanged and the field of view only changes minimally. But already through translations does the user have to transform between both frames of reference, his own frame of reference and the one in which the information is presented. When the AR viewpoint of the AR system differs from the viewpoint of the user, but shows the user with an avatar, a *tethered viewpoint* is used. Fully egocentric presentation for instance, can show an AR scheme from a car driver's point of view. Moving the point of view of the AR representation backwards some of meters an environmental view of the scenery can be shown, including an extra AR scheme of the own car. The more translational and rotational degrees of freedom are altered, the further moves the representation of the AR scheme to the exocentric end of the continuum. A well known alteration of three degrees of freedom often is used in 3D computer games. Besides the fully egocentric view on the scenery, the gamer can chose a tethered viewpoint. The view is transformed in a way that the point of view is moved backwards and slightly up, the camera is turned down so that the user can see the back of his own avatar. Here three degrees of freedom are altered, two translational and one rotational.

The continuum is not only defined by the 6 discrete degrees of freedom, but also by the continuous values of each

degree. Location between both ends also depends on the range, each single degree is altered. For instance, moving some meters along an axis has less effect than moving some hundred meters.

The more AR presentation schemes are located to the egocentric end of the continuum, the less mental workload is required to transform the information to the personal frame of reference. At the egocentric end of the continuum, no mental translation between both frames of reference is necessary. At the exocentric end of the continuum, most effort for translation is necessary, because the user has to know about the position of the virtual viewpoint relative to the own position and has to transform mentally between both frames of reference.

Complex transformations between two frames of reference are necessary, when the direction of the AR scenery is fully turned around. When, for instance, one sees his virtual character face to face from a leading viewpoint, doing a left turn leads to the character walking right (on the screen).

Egomotion in Displays. The community of ergonomics maps the type of mounting of the virtual camera presenting the information display in *exocentric* or *egocentric* manner to *Pursuit* and *Compensatory Displays* (Bubb, 1993). *Pursuit Displays* in general use an exocentric frame of reference. Here the point of view is rigidly bound to the environment. *Compensatory Displays* in contrast are coupled to the frame of reference of the user but do not necessarily have to present the information from an egocentric point of view. The point of view of the display can rather have a rigid tether to the user, mounting the camera in a way that it follows the *egomotion* of the user (Colquhoun & Milgram, 2000).

A special role of a *Compensatory Display* is defined by mounting the camera not rigidly to the user, but dynamically. Milgram and Colquhoun (Colquhoun & Milgram, 2000) describe such systems with the camera having a certain mass (and thus a certain inertia). A spring then mounts the camera to the user. Changes to the physical state of the user thus no longer directly and rigidly change the state of the display. The mass-spring-system smoothes the effects of the transformation and in particular compensates large translations, a rigid tether would generate due to rotations of the user. Lamb and Hollands (Lamb & Hollands, 2005) investigated this kind of display and compared it to conventional displays. Their results show a high potential for egocentric spatial awareness.

Direct vs. Indirect Referencing of Objects or Situations

The fifth class concerns the environmental situation and analyzes if an object or a situation is directly visible, if it is occluded in the field of view or if it lies outside the driver's field of view. The term *Type of Referencing* is used in later section to refer to this class. AR allows presenting information preferably in the field of view of the driver. In fact, visual information must reside in the field of view, otherwise it would not be perceived. Three categories of application are thus possible (Tönnis, 2008).

Indicating a Situation. Dangerous situations often occur within the field of view of the driver. In some cases, a driver's attention is focused on another stimulus and the driver does not capture the danger. Then, direct indication of the situation is possible by generating an AR scheme around the critical object to draw the driver's attention towards that object.

Indicating an Invisible Situation. A dangerous situation in the driver's field of view can also be occluded. AR can give a hint about the existence and location of that object.

Drawing Attention towards a Situation. Due to the forward motion of the car most dangers come out of the frontal region. Yet, dangerous situations can also come from aside or from the backside in some cases. The driver's field of view then cannot be used to indicate the situation directly. Thus no direct indication can be used to transfer information about the danger directly. Instead, information about the existence and location of the critical situation must be transmitted to the driver. Here the issue for AR is to guide the driver's attention towards the direction of the imminent danger.

Location of Presentation in Relation to Glance Direction

The sixth class deals with mounting information relative to the driver's glance behavior. Information, in addition to a location-fixed placement in the outside environment or a mounting on the car, can also be placed in relation to the glance direction of the user. Such systems require an additional glance tracking system. Expected benefits of such presentation are higher probabilities for information capture and, in consequence, lower missing rates. Information placed without knowledge of the driver's glance direction can be overseen because the driver never might look into that specific direction.

Design processes for driver assistance systems have to determine the most suitable area for such information transfer and the most intuitive presentation scheme for declaration of the information. An issue for the determination of the suitable area for presentation lies in dynamic movement of the user's glance. Especially the foveal area of sight which only covers a cone with an approximate opening angle of 2 degrees, can reach high speeds: when the driver refocuses to near distances or when the eyes perform a saccade, the foveal area of sight can move rapidly to another location. The same effect applies accordingly to the other visual areas of sight (parafoveal and peripheral) but due to their greater size, with less effect.

Short warnings surely can be placed directly in the foveal area of sight. Continuous presentation must not be placed in the foveal area as it would constantly occlude the area relevant for safe perception.

DESIGN EXAMPLES AND POTENTIAL CROSS-RELATIONSHIPS OF DESIGNS

The previous section collected different principles of how information can be presented. Various classes are there defined independently of each other and the dimension of each class is illustrated. Each localization of a presentation in each class states an independent variable for usability studies. To uniquely determine an effect in a usability study, only one such variable may be changed at a time.

Designers of AR systems are often not aware of all classes and unintendedly affect multiple independent variables in the design of their different variants. Besides awareness of these classes which is given through the last sections, this section illustrates common designs that introduce cross-relationships over combinations of classes. Each following section illustrates pair-wise combinations of all different classes. Table 1 gives an overview about the pairs that are discussed in subsequent. The six classes are inscribed horizontally and vertically. Each X marks a possible combination of two classes. Thus 15 pairs of class-combinations are generated. The X in row and column 3 is a special case

of presentation properties of spatial displays and therefore is also added to the collection.

| | | | | | | |
|---------------------------|---|---|---|---|---|---|
| Continuity (1) | - | | | | | |
| Representation (2) | X | - | | | | |
| Registration in Space (3) | X | X | X | | | |
| Frame of Reference (4) | X | X | X | - | | |
| Type of Reference (5) | X | X | X | X | - | |
| Glance Relation (6) | X | X | X | X | X | - |
| | 1 | 2 | 3 | 4 | 5 | 6 |

Table 1
Matrix showing all pair-wise possible Cross-Relationships

The subsequent collection of designs for driver assistance systems discusses these cross-relationships on selected examples. These examples were taken from the design phases of our systems: Plavšić et al. (2009), Tönnis et al. (2008), Tönnis et al. (2007) and Tönnis and Klinker (2006). We identified possible ambiguities for analysis during the design phase. The following sections discuss the potential prohibitions for unique attribution of effects to sources on these examples.

Focal and Perspective Distance vs. Contact-Analogy

One common problem in the design of AR applications does not have cross-relationships between two classes but refers to display technology. It thus is mentioned in this collection nevertheless.

An AR system developed for directing the attention of a car driver to a direction in the surrounding of the car was developed (Tönnis, Sandor, Lange, Klinker, & Bubb, 2005). In the test environment, the scenery of the surrounding was shown on a large projection wall of a driving simulator. The distance between the driver and the projection wall was 3 m. The presentation concept incorporated a 3D arrow floating in front of the drivers head, pointing in the desired direction (see Fig. 3).



Figure 3. 3D Arrow floating in the Field of View of the Driver

The arrow intentionally was planned to be shown at the distance of the front bumper, 2 m in front of the drivers head. To ease hardware setup, an extra display for the 3D arrow had been spared out. The arrow was thus shown on the same projection wall as the landscape scenery and the focal distance thus was also 3 m. The perspective distance was adjusted to 3 m to reach a correct perspective rendering of the 3D arrow.

Even if all constraints of optical properties had been met, this design generated ambiguities in understanding the location of the virtual 3D object. The 3D arrow transcribed a fully contact-analog presentation in the correct focal and perspective distance. The 3D arrow thus resided in a distance of 3 m in front of the driver. Most test subjects during the user

study estimated the position of the 3D arrow at this position but some interpreted the placing wrongly. They thought the arrow would be at the position of their own head. The test subject performed a mental translation between the original position of the arrow and their own position (see Fig. 4).

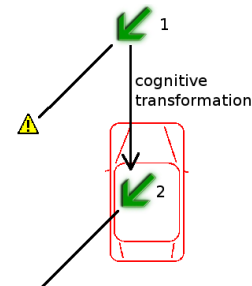


Figure 4. Incorrect Mental Transformation of the 3D Arrow to Position of Driver's Head. The green Arrow 1 shows the intended Position, Arrow 2 shows the interpreted Position of the floating Arrow

The study that compared targeting qualities between 3D AR concepts and conventional 2D presentation resulted in worse detection values for the 3D AR approach. In fact, many targets were shifted backwards. As Fig. 4 shows, the mental translation of the 3D arrow kept the pointing direction, thus aiming to a more rearwards shifted target.

An extended version of the 3D arrow was mounted to a pole in a later experiment (Tönnis & Klinker, 2006). The pole mounted the arrow visually to the front bumper. Also a separated HUD was incorporated, physically decoupling the focal planes of the landscape scenery and the visual aid. The 3D arrow no longer appeared on the projection wall but had its own placement in the 3D space between the car body and the landscape scenery. The arrow thus appeared to have its own placement at a certain position in front of the driver. The decoupling and the mounting pole together eliminated the effect of the mental transformation of the 3D arrow to another location.

The findings gained through the two subsequent studies show that, even if the concept keeps the same, the kind of presentation matters. The 3D arrows in both variants were, according to the focal plane and the pointing direction, at the same position but were evaluated differently. The adding of the pole generated a different understanding of the presentation. Designers have to be aware that even if focal and perspective properties are adjusted correctly, perception and mental understanding of a visualization may differ significantly.

Registration vs. Type of Referencing in Different Frames of Reference

The guidance system for a car driver's attention enables investigation of cross-relationships between spatial registration of information objects, their frame of reference and the reference of the object to the related (real) object. This cross-relation is explained on the application from the previous section (Tönnis et al., 2005). There, a 3D arrow is used to guide a car driver's attention towards a certain direction. To test the system, a comparison to a more conventional system showing the car and its vicinity in a small sketch from a bird's eye perspective (see Fig. 5) was conducted.

While the according study yielded better detection performance for the bird's eye perspective than for the 3D arrow, the quality could only be measured for the whole system variant. It keeps unclear which of the following changes in principles of presentation attributed to the different results.

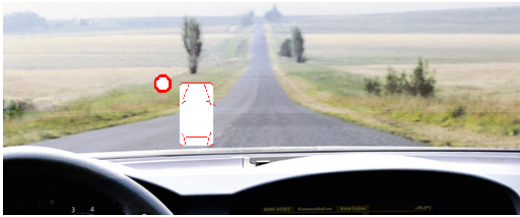


Figure 5. 2D Bird's Eye View showing the Position of a Target

Both information objects had a different registration in space: the bird's eye scheme is unregistered while the 3D arrow is contact-analog. The bird's eye scheme shows the information in exocentric egomotion while the 3D arrow is shown in a fully egocentric frame of reference. The bird's eye scheme refers to a certain location in the own car's vicinity while the 3D arrow can only point to a specific direction. How these three differences generate cross-relationships will now be discussed in more detail.

Registration in Space vs. Frame of Reference. The bird's eye scheme shows the car from a top down perspective. The presentation incorporates an exocentric frame of reference which shows the own car with its vicinity in egomotion. The sketched car always faces up. The presentation scheme is not registered with the environment. It shows an abstracted „world in miniature“. The 3D arrow in contrast is spatially registered with the environment. It embeds into the view and appears as a contact-analog element of the real world. The scheme therefore is necessarily shown in a fully egocentric frame of reference.

Type of Referencing vs. Frame of Reference. The two schemes not only provide their information in different frames of reference, they also use different types of referencing to the object of concern. The bird's eye perspective shows the own car and its vicinity. A marking in the overview sketch gives a hint about the *location* of the potential hazard.

The AR scheme in contrast suffers under the fact that the object of concern does not necessarily reside in the field of view of the driver. A direct indication of the object therefore is not possible in cases, where, e.g., the object is behind the own car. The AR concept was designed to have one visualization to guide the driver to any point of concern. Different visualizations were to be avoided to, among other things, reduce time for interpretation of different symbols. Thus the resulting visualization had to be reduced to the common denominator, which here is referencing to the direction of the situation. The 3D arrow points toward the direction of the potential hazard. The driver has to follow the pointing *direction* until his glance aims at the object of concern.

Here a further difference in the concept of the two visualization schemes is apparent. The bird's eye view shows the location while the 3D arrow only gives a direction.

Registration in Space vs. Type of Referencing. The third affection of classes pertains the relation between registration of the objects and their kind of referencing to the object of concern. Both placements in the corresponding classes have been mentioned in the previous sections, but their direct relation has not been investigated. The ambiguity prohibiting exact attribution of causes for different results also exists in the combination of different object registration together with different types of referring to the object of concern.

Combined Cross-Relationships. Both visualization schemes incorporate each three differences in their general design. The bird's eye scheme is unregistered and shows the information in exocentric egomotion referring to a certain location. The 3D arrow is shown in a fully egocentric frame

of reference in a contact analog display and only informs the driver about the direction to the object of concern. User studies thus can only determine how one variant can be handled with respect to the other one. The analysis can not determine which modification to one of the dimensions has been the major cause for differing effects.

Representation vs. Type of Referencing

Besides an information object's registration in space also its type of representation can generate cross-relationships to other classes of principles for information presentation. An example to illustrate the potential complications compares the designs of two different projects that investigated assistance concepts at intersections.

The Intersafe project (Fürstenberg, Kay, 2006) proposed a 2D information icon (see Fig. 6) to show the risk of a hazard to the driver.



Figure 6. The Intersafe Display Fürstenberg, Kay (2006) showing an unregistered general warning Level

Plavšić et al. (2009) developed a 3D derivate in the design phase for a study concerning safety at intersections (see Fig. 7).



Figure 7. The Street Arrow encodes the Location of a potential Hazard in its Appearance

Fig. 8 shows the so called „street arrow“ and its spatial registration with the environment.



Figure 8. The Street Arrow transfers its information spatially registered to the Environment

Both symbols carry different inherent information. The intersafe symbol displays a general warning level. The shown images illustrate this on a left turn situation. The 2D information is not registered to the environment and thus is kind of indirect reference to the current environmental situation. The 3D street arrow relates more fine-grained bits of information to corresponding locations on the intersection. The display therefore is a direct reference to the current situation in the intersection.

A hypothesis for an evaluation might state that direct referencing is superior to indirect referencing. This hypothesis could not be validated when these two variants are tested because they also incorporate different shapes for presentation.

Representation vs. Registration

While the main focus of the previous section lies on the type of referencing, the relation to the spatial registration of the information already has been mentioned there. This shall be deepened in this section by investigating different design variants that incorporate either a 2D and a 3D representation but are also registered differently.

An example for a 3D unregistered presentation is a „world in miniature“ (see Fig. 9). It shows a computer generated model of the outside environment. The model appears to float at a fix position in the HUD but displays symbolic content.



Figure 9. A 3D unregistered Information Display showing a „world in miniature“

To give an example of a 2D registered presentation, one might argue that every 2D information is always spatially unregistered per definition and therefore never can be registered to the environment. Fig. 10 (Plavšić et al., 2009) therefore illustrates a 2D information that uses principles of contact-analog registration. The orientation of the 3D arrow and its placement behind the traffic lights show that the information is placed in a distance according to the distance of the object of concern, which in this case is an indirect reference to a car occluded by a truck.

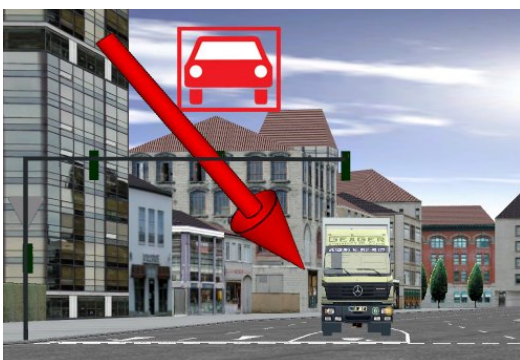


Figure 10. A 2D spatially registered Information Display combined with a 3D Arrow

This design shows that indirect referencing is possible in combination with 2D symbolism.

Representation vs. Frame of Reference

Relationships between the representation of an information and its frame of reference are best illustrated by the various concepts that are currently under development for navigation systems.

Available for a longer time are navigation systems that provide their information in 2D. Most of them allow switching the map-like presentation between north-up and face-up. The north-up presentation uses an exocentric presentation where only the position of the own car is kept in the center of the display. The face-up presentation is a compensatory display turning the map in a way that the representation of the own car always faces up. Driving a curve lets the map rotate around the spot of the own car. These displays show their information in an exocentric frame of reference but in egomotion of the car. As mentioned in the definition of the class for the frames of reference, the term „exocentric“ refers to the use in the computer graphics domain. Researchers in ergonomics use the term „egocentric“ when the display is compensatory. To avoid ambiguities we use the term „egomotion“ in addition.

Reduced versions of such face-up navigation systems are integrated into HUDs. As Fig. 11 shows, symbols with concern to the next action to take are presented with respect to the own car. The 2D display still is in an exocentric frame of reference, but in egomotion.



Figure 11. Symbolic 2D Navigation information shown in a HUD; courtesy of BMW

Upcoming systems like the iNavi (Thinkware, 2009) system present the navigation information in 3D (see Fig. 12). Here the view is generated in a way that the point of view is similar to the driver's point of view. The driver has an egocentric point of view even if the display is spatially unregistered. Other variants place the point of view on a rigid tether so that an avatar of the own car can be seen on the display. Such displays thus again use an exocentric point of view in egomotion.



Figure 12. A tethered 3D Navigation System in Egomotion (Thinkware, 2009)

HUDs allow integrating navigational information into the surrounding environment. The information can be shown either in 2D or in 3D. Fig. 13 shows a design variant of a contact-analog 3D navigational arrow (Tönnis et al., 2008). Such a display is fully egocentric.



Figure 13. A fully egocentric 3D Navigation System



Figure 15. A 2D spatially registered Lane Departure Warning

Cross-Relationships with Discrete or Continuous Information

The fact that the HUD allows integrating virtual objects into the surrounding environment offers various opportunities to change the kind of information presentation from discrete events to continuous information and vice versa. Lane departure warnings, for instance, can be substituted by continuous information reflecting the quality of the lane keeping. Concepts between unique or continuous presentation generally differ to a large extent and therefore require deep investigation to reach the optimal design.

One example is used in the upcoming section to illustrate different approaches. This example incorporates a continuous presentation of the physical behavior of the own car. A so called braking bar shows the longitudinal and lateral behavior (Tönnis et al., 2007). Fig. 14 shows this bar. The bar is a 3D object that is continuously visible. It is contact-analog registered with the environment and therefore uses an egocentric frame of reference. It references to the current situation in a direct manner as its distance to the own car increases when the driver accelerates. The bar displays the current braking distance to a halt when the brakes are fully pressed. Turning the steering wheel turns the bar accordingly. The bar thus shows the halting point dependent to the driven speed and the setting of the steering wheel.



Figure 14. A Braking Bar showing the halting Point and the driven Curve Angle

The braking bar is not necessarily a warning system, it rather is a system that intends to increase the situational awareness of the driver by showing him how his car behaves. It also can be a warning system, when, e.g., the bar changes the color according to an upcoming lane departure or a too low safety distance.

Continuity vs. Representation. Discrete warning systems are the alternative to systems that intend to raise situational awareness. A system that is spatially registered to the environment in the same manner as the braking bar is a lane departure warning as shown in Fig. 15. The red triangle appears at the location in the surrounding of the own car, where the lane will be crossed. The driver thus can overlook the distance up to this location and can plan his reactions accordingly.

The main difference between the continuous information

of the braking bar and the discrete information of the alert is that the alert takes the driver out of the control cycle of the driving task unexpectedly. A 2D representation can be supportive for fast perception because the shape of the object has an easy symbolic style. Such a symbol can have the potential to keep the time short in which the driver is out of the loop of the control circuit. The potential benefit of a spatial registration in a warning situation is that no additional mapping between the information and the location is necessary.

Continuity vs. Registration in Space. Another system that monitors the lane keeping behavior is the MobilEye (MobileEye, 2009). This after-sales product has a small display that is mounted on the dashboard (see Fig. 16), but its information could also be placed in a HUD. When a lane border is approached, the corresponding lane delimiter on the MobilEye display gets illuminated and starts blinking. Like many warning systems, this system also uses acoustic information to notify the driver about the existence of an actual danger.



Figure 16. A 2D Lane Departure Warning (MobileEye, 2009)

This information is not registered in space. Instead, the driver knows from where to perceive the information because the display is mounted on a fix position known to the driver.

Continuity vs. Frame of Reference. Presentation in an exocentric frame of reference like with the MobilEye system requires the driver to mentally transform the viewpoint of the information display to his personal frame of reference and his field of view. This procedure requires the driver to build a mental model of the presented information and to align this model to the environmental setting.

Interpreting and exocentric frame of reference may require the driver to repeatedly look at the visual information to compare the mapping to the real setting. Appearance times or blinking frequencies of the scheme should take this fact into consideration.

Continuity vs. Type of Reference. To give an example for non direct referencing of a situation, the 3D arrow application is recalled here again. In this concept, a 3D arrow appears in a critical situation to guide the attention of the driver to a certain direction (see Fig. 3). This concept was postulated because a danger can come from any direction. The system does not intend to increase spatial awareness, its focus is rather placed on short reaction times for spatial understanding. The system always gives an indirect reference to only guide the attention of the driver.

The braking bar scheme actually does not directly tell that the lane border is to be passed, but the presentation in its contact-analog manner shows that the bar crosses the lane border. The contact-analog overlay with reality makes this information directly visible.

Glance Behavior related Information Presentation

With increasing tracking performance and quality, glance tracking systems have the potential to gain further interest for application in safety systems. While first such systems are already under development to determine if a driver falls asleep, such systems have the potential to support visual assistance systems in a new way. Their application area in the automotive domain has the potential to enable displays to move with respect to a driver's viewing direction.

The human eye has different areas of perception with different degrees of sharpness which are important for the design of glance related driver assistance systems. The *fovea centralis* (yellow spot) is the area, where the eye has the sharpest perception. It is located at the intersection point of the retina and the extension of the central glance axis. Its field of view is about 2 degrees in a cone. Only objects in this cone can be seen sharply. Sharp and clear vision is important, when, e.g., the speedometer is read. To gather information, the foveal field of view must be turned to the direction of the information. The *parafoveal field of view* furthermore is a second cone, surrounding the central foveal field of view and ranges from 2 degrees to 10 degrees. Here, colors, contours and contrasts can be perceived. The *peripheral field of view* starts in angular values greater than 10 degrees to the central glance axis. Peripheral perception enables static and dynamic orientation as well as perception of movements and changes in brightness. Size and direction of objects can be estimated through perception in the peripheral area (Kornhuber, 1978). Fraise (Groner, Rudolf and Fraise, Paul, 1983) found the threshold for peripheral perception of movement between 1 degrees/s and 2 degrees/s.

With this information at hand, some factors are of concern for the development of ADAS systems. These will be discussed in subsequence. The discussion follows the order of the classes of presentation principles.

Glance Relation vs. Continuity. Presentation concepts for visual information that are related to the line of sight should adhere the perception constraints of the human eye, such as the areas of different perception. To discuss such principles we assume that the information for the moment has a fix angular value to the center line of sight. Information presented with a fix angular offset to the center line of sight follows the movement of the eye. The information moves accordingly when the driver looks to the side. An information presented, for instance, in a 5 degree offset to the right always remains in that angular distance no regard where the driver is looking. Later sections will discuss varying angular values for information presentation.

Presentation schemes that must be perceived clearly must lie in the foveal field of view. Large simple objects can also reside in the parafoveal field of view. Any information whether continuous or discrete that must be perceivable to at least a certain degree must therefore be presented near to the line of sight. The peripheral field of view can only be used to give a hint about the existence of information. Discrete information can use such a peripheral cue by presenting the information in a way that is recognized to be there. Large changes in an object's size and brightness and its movements can be used to transfer that information.

Glance Relation vs. Representation. Visual information which is presented in respect to glance behavior has no direct mounting to the environment. In fact, there can be a reference point to which the scheme refers to, but the scheme itself is only bound to the glance of the user. It therefore remains to be explored which kind of representation operates for such visual information that is floating through the space.

Glance Relation vs. Registration. Concerning spatial registration, the depth perception of human eye was introduced as the main reason why any AR information should be presented in the correct focal distance. This way, the eye does not have to perform any focal accommodation. Registration issues have been discussed in previous sections. This section therefore will discuss registration of information in the field of view relative to the line of sight.

AR presentation with respect to glance behavior has been introduced with a certain, fixed offset to the eye's central line of sight. Adaptation to glance behavior raises the question whether information presentation can be dynamically floating between the different fields of view. To give an example: any kind of location-fixed information is such a floating presentation. A certain location or an object is highlighted in the peripheral field of view. The driver notices the change in the appearance and turns his head to look at the spot or object. The information moves through the peripheral and the parafoveal field of view while the head turns. When the driver looks at the highlighted object, the AR presentation has reached the foveal field of sight.

An example that relates to glance behavior is a specific information. If such an information would appear in the foveal field of sight, the spot where the driver looks at would spontaneously get occluded. To allow the driver to perform timely planning of information perception by himself, the information instead appears some degrees off. The driver can then plan when he wants to access this information. When he now turns his head the information does not keep its offset, it rather keeps in its position. The information seems to be mounted to the own car on a rigid tether. This way, the driver can access the information.

Information presented this way has a potentially higher chance to get noticed because it appears near the area where the driver looks at, no regard where that is.

Glance Relation vs. Frame of Reference. As mentioned in the section discussing Glance Relation vs. Representation, a presentation scheme does not have an alignment to the physical reality. Besides a potential reference point there is no mounting of a visualization in the outside space.

It also remains subject of further investigation to determine which frame of reference serves which kind of application. One general assumption can be made in advance. If a presentation is mounted to the driver's glance, and this information has a reference to the outside environment, it should use a compensatory display. This can be explained on an example. Assumed, the display shows a „world in miniature“ which is rigidly mounted to the glance of the user. At the moment the scheme appears to the user its orientation fits to the surrounding. The north direction of the „world in miniature“, for instance, faces to the north direction of the real world. The visualization only has a correct alignment in that viewing direction. When the user now turns his head, does the „world in miniature“ stay fix with respect to the user, but turns in respect to the environment. Directions would change and the user would have to transform between both frames of reference newly when he looks at the presentation scheme in a different viewing direction.

Glance Relation vs. Type of Referencing. The section

that discussed glance relation vs. registration introduced a first step for dynamic adaptation to glance behavior for unobtrusive information presentation. Such a dynamic behavior can be extended to enable different types of referencing. Dynamic motion of presentation schemes has the potential to guide the attention of a user to a certain direction and even to a certain location. Such a location can even be outside the normal field of view, probably in the back.

Such a guiding scheme can appear in the peripheral field of view. There, the guiding scheme has to possess features that increase the probability of visual perception in the peripheral field of view such as blinking and motion. Because of its peripheral placement is the object unclear to perceive. When the driver turns his head to look at this peripheral object, the presentation starts to move towards the desired target direction when it is in a much wider turn. The AR presentation stops in the place of the target when reached. The glance of the driver catches up and the AR scheme comes through the parafoveal field of view into the foveal field of view where it can be perceived.

CONCLUSION

The HUD technology increases the opportunities for information presentation. Information can not only be presented nearer to the line of sight, but also in a larger focal distance. Both factors reduce the time for information perception.

Available HUDs still have a presentation area too small for AR, but future development might enable large scale HUDs that are fully capable of presenting information embedded into the environment. The HUD extends the presentation space by an additional dimension. Information now can be presented in three dimensions. Information objects can not only be rendered in a 3D perspective shape, but also can be placed in different focal depths.

The fact that the information can be spatially related to the object of concern introduces new opportunities for fast and efficient information presentation but also generates new issues. Design principles from classic 2D displays are no longer applicable in their full extend. The main reason lies in the altered motion behavior of visualized objects. Compared to a in-car display, a HUD has no static background. Instead, its image plane lies in the outside environment which makes it moving when the car moves. As a matter of fact, the frame of reference of objects in the HUD is different. An object shown in a way that appears to be standing still on the ground at a certain position moves over the HUD display.

The extended design space of the HUD has to be explored. Different principles can be applied to present such information. The first major part of this paper therefore collects six widely used classes of principles for information presentation and explores each dimension. Any information displayed in a HUD generally has a footprint in each of these six dimensions. The information is either continuous or discrete, is displayed in 2D or 3D, is spatially registered to the environment or displays unregistered symbolic content. The presentation of the visualization is shown in a specific frame of reference and uses a certain type of visualization to refer to a specific object or a situation. An outlook to glance related information presentation concludes the survey of the principles for information presentation.

It has to be determined which combination of principles operates best for a specific task. Yet, ADAS systems can be developed and can be tested in comparison to conventional displays. The comparison can show whether a variant performs better than another variant. What remains an issue with

this approach is that the HUD presentation or its variants often have multiple different placements in the different dimensions of the classes. Reasons, why one variant is evaluated differently to another variant can not clearly be attributed to an independent change in one class of presentation. This possibly leads to a less optimal design.

The second major part of this article therefore examines various ADAS application and their cross-relationships between pairs of presentation classes. The classification of different design variants of ADAS systems and the mentioned double affection of two classes of presentation generates awareness for the dimensions.

What remains for future work is that all classes must be investigated in detail to determine which placement in a specific dimension provides the best result for the given task of the driver.

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