

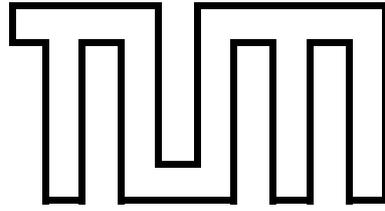
FAKULTÄT FÜR INFORMATIK
DER TECHNISCHEN UNIVERSITÄT MÜNCHEN

Diplomarbeit in Informatik

**Presentation Concepts for Conformal
Navigation Systems**

Leslie Klein





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Presentation Concepts for Conformal Navigation Systems

Anzeigekonzepte für kontaktanaloge Navigationssysteme

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Submission Date: May 2008



I assure the single handed composition of this diploma thesis only supported by declared resources.

Munich, 15th of May 2008

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Zusammenfassung

Navigationssysteme sind heute nahezu Standard bei der Ausrüstung von Neuwagen. Während solche Systeme einseitig wertvolle Unterstützung und Entlastung des Fahrers bieten, können sie andererseits vom Fahren ablenken und stellen so eine potentielle Gefährdungsquelle dar. Auch wenn eine Vielzahl von Ansätzen entwickelt worden sind, um die Ablenkung des Fahrers zu verringern, bleiben zwei Probleme bestehen: Der Fahrer muss zur Erfassung der angezeigten Information seinen Blick vom Strassengeschehen abwenden und er muss diese Informationen mental verarbeiten, was ein gewisses Maß an kognitiver Leistung erfordert. In dieser Diplomarbeit wird deshalb die Nutzung von Augmented Reality als Grundlage für zukünftige Navigationssysteme untersucht. Augmented Reality bietet in Kombination mit integrierten Head-Up-Displays einen vielversprechenden Lösungsansatz um das Strassenbild mit sogenannten "kontaktanalogen Navigationshinweisen" zu erweitern. Hierbei erscheinen in das Head-Up-Display eingeblendete Navigationspfeile als auf der Strasse liegend und sind dadurch scheinbar in die reale Umgebung eingebettet. Die Umsetzung dieses Ansatzes führt zu einer Vielzahl von neuen Forschungs Herausforderungen. In dieser Arbeit wird zum einen das graphische Design und dessen Umsetzung betrachtet und zum anderen die Implementierung eines Systems mit dessen Hilfe die Grenzen solcher Anzeigesysteme in Bezug auf Graphikdesign und Technologie evaluiert werden können. Besonderer Schwerpunkt ist hierbei die Erforschung der durch den optischen Aufbau gegebenen Grenzen der Anzeige. Hierzu wird im Rahmen einer empirischen Studie der Schwellwert der Anzeigedistanz ermittelt sowie die Frage untersucht, inwieweit dieser Schwellwert durch geeignete Anzeigekonzepte verbessert werden kann.

Abstract

At present, various types of navigation systems are integrated into the car almost as a standard. While these systems promise to serve a valuable support, they represent a challenge by reason of being hazardous if interfering with the driving task. Although various improvements to reduce the driver's workload have been made during the last decades, they still face two common problems: On the one hand the driver has to take his eyes away from the street scenery to catch navigational information and on the other hand cognitive effort is required to interpret abstract metaphors on the navigation display and translate them to the real world. In this thesis we investigated Augmented Reality based techniques as a novel approach for user interaction in terms of navigation systems. This technology in combination with an integrated Head-Up Displays technology provides an attractive approach to augment the street scenery with conformal navigational aids. Conformal navigational aid's are virtual elements (e.g. arrows) for route guidance information, which appear to be aligned with the street and are thereby seemingly integrated into the real environment. With this approach of displaying such navigational aids into the Head-Up Display, that these appear to be part of the street scenery a variety of new research challenges arise. In this work special attention is given to the graphical design and development of conformal visualization schemes and to the implementation of a system to evaluate the limitations of such schemes in terms of the design and technology. Furthermore the identification of indication limitations, induced by the optical setup, was considered to be of high importance. Thus a usability study has been performed to identify a distance threshold for conformal indication and whether this threshold can be influenced by the design of the presentation schemes.

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1 Introduction

Motivation of using Augmented Reality for Route Guidance and Scope of the Thesis

In the last years, due to the rapid advances in hardware technology, computer technology has become probably the most important driver for innovation in modern cars. Already in 2003, premium cars have been equipped with about 80 embedded systems and a total software size of about 60 MB [8]. In particular so called Advanced Driver Assistance Systems (ADAS) and In-Vehicle Information Systems (IVIS) have been introduced in order to provide comfort to their users while at the same time enhancing traffic safety. ADAS are systems to help the driver in his driver process, like Adaptive Cruise Control (ACC) or Lane change assistance, whereas IVIS are systems which help the driver by providing information, for example about routes, traffic congestion and accidents. Since these systems interact with their users in various ways they can be potentially distractive. Therefore appropriate technologies and principles for user interaction have to be adopted. In this thesis we investigate Augmented Reality based techniques as novel approach for user interaction in terms of navigation systems.

The first section of this chapter outlines the motivating aspects for this work. This comprises a survey about existing solutions for navigation systems with respect to their main limitations and introduces to a novel approach for route guidance indication. The basic technologies, Augmented Reality and Head-Up Displays, used for realization and the main challenges which accompanies with this approach are mentioned. The last section gives an overview about the scope and structure of this thesis.

1.1 Motivation

Navigation is a fundamental subtask of driving [25, 10]. Thus the integration of navigation systems may have an enormous benefit to driving safety and convenience, since they exempt the driver from wayfinding so that he can pay more attention to traffic, in particular in unfamiliar areas.

Navigation systems Therefore navigation systems are integrated into modern vehicles almost as a standard. Navigation systems acquire position and orientation data of the vehicle on a road and can guide via a sequence of way-points to the desired destinations. Guiding to the next way-point means the visual and/or auditory indication of navigation relevant information. This comprises information about the location where to turn-off, the direction and the distance to the specific point. Different approaches to present these informations

to the driver are currently available. These can be classified into map-based, turn-by-turn guidance or a combination of both [13].

Map-based route guidance is provided by an aerial view onto a two- or three dimensional geographical bird's-eye map, centered to the driver's current position and showing highlighted routes. Support for orientation on it is provided by rotating the map, so that the car and the map are heading to the same direction. Shown in Figure 1.1(a)



(a) Map-based navigation system (Courtesy of TomTom) (b) Symbolic turn-by-turn navigation system (Courtesy of Telenav)

Figure 1.1: Navigation systems

Whereas turn-by-turn systems indicate the next point where to turn or the direction to there by showing a simple, flat arrow and additionally give information about the distance to the maneuvering point, see figure 1.1(b).

Solutions which provide a combination of both change the presentation depending on the distance to the maneuvering point. They provide map-based guidance as long as the turning point is out of the driver's sight and alternate to turn-by-turn indication for short-range movements close to the specific turning point.

A further approach is the indication of location and direction of each turning by using voice instructions [23, 28]. Acoustic guidance is mostly combined with visual information to give the driver the opportunity to catch missed navigation information. Furthermore a lot of research has been done to enhance the effectiveness of voice instructions by the use of landmarks (e.g. traffic lights, churches, petrol stations) instead of distance information [15, 14].

Main problem of navigation systems While in-vehicle systems promise to serve a valuable support regarding comfort and safety, they represent a challenge by reason of being hazardous if interfering with the driving task. Horrey and Wickens [26] showed that human's have the ability of controlling the movements of a vehicle and performing a secondary side-task at the same time. Although the driver is forced to glance inside the vehicle to perceive the provided navigation information, he is able to manage vehicle control by peripheral vision. However if two or more tasks are performed concurrently, there is an amount of inter-

ference between the tasks and this results in an increased response time to critical hazardous effects.

Although all such navigation systems are aimed to support the driver in his driving task, by reducing driver's cognitive load, they face two common problems:

Firstly, the glance-away problem, the driver has to take his eyes away from street scenery to catch navigational information.

Secondly, cognitive effort is required to map these route data to his real environment.

Additionally, increasing traffic and the fact that more and more supplementary systems are integrated into the car requires to improve existing solutions in order to reduce the driver's mental workload. Regarding user interface technologies two promising candidates are Head Up Displays (HUDs) and Augmented Reality (AR).

Head-Up Displays Addressing the first issue mentioned, the glance-away problem, the placement of in-vehicle navigation displays is a key design consideration. The advantage of using a HUDs instead of in-vehicle displays has been evaluated in various research [2, 12, 11, 46]. Due to this, head-up displays provide a powerful alternative to conventional displays. Head-up displays (HUDs) enable presentation of information in the drivers windshield thus into the drivers field of view. This technology, widely used in Aviation, is an approach to allow the driver to detect potential hazards in peripheral vision whilst glancing at the display. Already integrated into many vehicles (see Figure 1.2), HUDs enable the driver to quickly read offered information, like speedometer or navigation information. The information appears above the engine hood, so firstly the driver does not need to turn his head which results in a reduced glance-away time and secondly the focal accommodation time becomes shorter as the eyes don't have to focus to information inside the car. Up to now merely symbolic indication for navigation is provided. Though this is an approach to diminish, but not to eliminate the effect of missing important external hazards. The driver still has to adjust his eyes to another focal depth when viewing from street scenery onto the HUD. Furtheron driver's workload is not reduced, because the problem of mapping route information to real world still exists.



Figure 1.2: Automotive HUD (Courtesy of BMW)

Augmented Reality An new approach to overcome these limitations, is the use of Augmented Reality (AR) technology. AR is a technology by which the humans view of real world is augmented with virtual information. In other terms, AR enables one to make virtual images appear before the viewer in well specified locations in the real world image.

The combination of integrated Head-Up Displays combined with Augmented Reality technology provides an attractive approach to augment the street scenery with conformal navigational aids. Navigational arrows appear to be aligned with the street and seemingly integrated into the real environment. Conformal route guidance information is displayed in the same frame of reference as the real-world information [41]. The need of shifting between 2D and 3D representation mentally is eliminated. Development of Augmented-Reality applications within Head-Up displays seems to be a promising solution: The driver's workload is reduced, because he does not need to transform route information *and* he does not have to adjust to another focal depth when viewing from street scenery onto the provided information.



Figure 1.3: Conformal presentation of navigation information

1.2 Research Challenges

The presentation of conformal route guidance information so that it appears to be part of the street scenery poses new research challenges.

Providing location fixed route guidance implies that these aids have to be displayed by providing depth cues. This means they have to be displayed with a three-dimensional sensation of distance, so that the driver has an understanding of the aids position within the three-dimensional world. Additionally to enable the driver to anticipate which kind of maneuver he has to accomplish, it is essential that the navigation information is perceptible in great distance.

Furthermore, in order to reduce the driver's workload in comparison to common navigation systems route guidance information must be designed as natural and intuitive as possible.

Based on these requirements the following challenging key issues are:

- Providing **perception of depth** to show the driver *where* to turn.

- Providing **perceptibility in distance** to enable the driver to know *what* kind of maneuver he has to accomplish.
- Providing **intuitiveness** to enable the driver to understand *what and where* easily.

According to these principles an effective solution for human perception and for information processing has to be provided. Due to these issues the development of conformal indication postulates special requirements to the display device as well as to the design of the navigational aids.

Display constraints The visual capability supplying perception of depth and perceptibility in distance by means of current HUD technologies is subject to limitations.

- Perception of depth: Virtual information has to be placeable at different distances to the driver. Since there is no possibility providing an adjustable focus depth, the display can only provide one fixed-focus depth. However, placing the image plane in specific distance to the driver is an approach to approximate to the required focal depth. Further details about human's depth perception is given in a later section 2.2.3.
- Perceptibility in distance: With respect to the second mentioned issue there is a need that a wide range of possible indication distances can be covered. But the perceptibility of objects in distance is related to the spatial resolution of the display, which means displaying navigational aids at a great distance is limited to some extent.

Design constraints Some improvements to counteract the limitations induced by the display device can be implemented by the design of the visualization schemes.

- Perception of depth: In terms of providing depth perception for location fixed arrows, some allusions can be provided by the design and rendering of the navigational aids. Which means supporting depth perception can be improved by cues which are independent of the display device.
- Perceptibility in distance: Design constraints concerning the improvement of perceptibility of the given information are crucial and unfortunately at the same time elusive aspects of research. Up to now no research has been done to identify or define important aspects to enhance the perceptibility. Considerations which visualization scheme does achieve the highest perceptibility in distance can only be done in an intuitive way and have to be proofed.
- Intuitiveness: Providing intuitiveness of the provided information is complex issue, especially in the context of conformal indication, where no standards are set. Navigational aids must be designed efficient, easy to learn and satisfying to achieve the desired goal that concepts becomes easily understandable.

Due to all this, the development of navigation systems with conformal route guidance is a complex and challenging task. The constraint of being non-interferent with the primary task of driving is the most essential goal in the development of new in-vehicle technologies. This constraint in combination with the requirement that in-vehicle systems have to be usable for the universal user population with limited training opportunities and within different environmental conditions make these systems one of the greatest challenges the human factors

design is faced today [33]. All careful and well-defined designs can nevertheless fail their intention, or can be impaired by technical limitations. Usability studies have to proof whether the Augmented Reality indication itself does not generate workload. Determination whether conformal indication keeps both conditions, reducing the visual and the cognitive demand, has to be verified. Especially with regard to the fact that misdetermination of the influence of such representation can lead to distraction and thereby be the source for accidents. Physical and cognitive performance and efforts of humans in relation to new technologies as well as the technological limitations itself have to be identified. In particular the perceptibility and the perceivability of route information have to be tested to sustain the intention of reducing visual and cognitive demand. Thus, there is the need for a solution to study human and new technology in conjunction to identify benefits and limitations on both sides.

1.3 Scope and Structure of this Thesis

This diploma thesis gives attention to the design and evaluation of conformal route guidance information and on that account includes four major sections.

Fundamentals The first part of this thesis introduces the relevant areas which have to be considered for the development of navigation system with conformal route guidance information (chapter 2). This chapter discusses the technological aspects as well as the theoretical, like physical and psychological backgrounds, for the topics of this thesis. This includes the paradigm and use of Augmented Reality (section 2.1) and further on human factor aspects (section 2.2) in terms of driving and distraction. Additionally human factors related to human depth perception are mentioned. After introducing these topics this chapter closes with a brief outline of empirical evaluation (section 2.3) which is essential for correct interpretation of data gathered from the experiment at the end of this work.

Design Concepts The second main chapter is dedicated to the design and implementation of conformal navigation indication (chapter 4). The topics covered in the previous chapters are incorporated and discussed within the context of designing conformal route guidance information to achieve the desired purpose of those systems making travel more efficient and safer. Some of the design guidelines can be drawn upon other research, but by reason of being a new approach for navigation systems, constraints and limitations for the design have to be identified. The first part of this chapter states general considerations concerning conformal visualization schemes (4.1). This is followed by a discussion about location- (4.2), car-fixed (4.3) and hybrid (4.4) approaches. But beside all these theoretical considerations special emphasis has to be placed on the limitations induced by the display's resolution mentioned previously.

System Setup The third major section (5) provides an explanation about the hardware setup used as prototypical construction to serve as test environment (5.1). Furthermore within the scope of this thesis an application for preliminary studies has been implemented. The intention of this system is to provide a reasonable test environment for the evaluation of conformal visualization schemes. The structure of this application will be explained

(5.2). Additionally, to have the possibility for the contemplation of design concepts like they would appear in real world a three-dimensional virtual world with different and complex street combinations had been implemented.

Empirical Evaluation By reasons of the indication limitations induced by the optical setup one important part of this thesis is to determine which relationship between the selected visualization scheme and the highest perceptibility in distance is the best. Thus, this section (6) covers the whole usability study which has been performed for determination of these indication limitations. This comprises the explanation which of the visualization schemes were chosen for the experiment (6.1) and the list of hypotheses which were setup before the experiment (6.2). Furthermore the whole setup and procedure of experiment is explained (6.3). It concludes with the empirical evaluation (6.4) of gathered data and a discussion about these results.

2 Fundamentals

Theoretical Background: Augmented Reality, Human Factors and Empirical Evaluation of Usability Tests

In this chapter the relevant background issues required for this work are introduced. These are Augmented Reality and the important aspects referring to Human Factors Design. Providing a usable conformal system, which enhances the driving safety requires validation on the basis of sound usability studies. Therefore basics for the evaluation of the experiments, which were executed for this thesis are described at the end of this chapter.

2.1 Augmented Reality

After an introduction into the concept of Augmented Reality the main technologies for implementing AR based systems are introduced. These are tracking technologies, advanced display technologies and techniques for the real-time rendering of images.

2.1.1 Definition

The idea of Augmented Reality (AR) is that an observer's experience of an environment can be augmented with computer generated information. In comparison to Virtual Reality (VR) Technologies, by which the user is completely immersed inside a synthetic environment, AR allows the user to see real world with virtual objects superimposed. In terms of the Reality-Virtuality (RV) Continuum [30] which presents a concept that encompasses all variations and combinations of real and virtual objects, AR is denoted to be a sub-category of Mixed Reality (MR), see figure 2.1. The augmentation placed correctly in space, appears to be part of the user's world. Synthetic information melts into the real environment. The augmented Information can address all senses, but in general is used for visual presentation.

A general definition is given by Azuma [3] where augmented reality systems are defined as systems that have the following three characteristics:

- **Combines real and virtual:** This point emphasizes the distinction to VR, that the user can see both, the virtual objects and real environment, rather than completely replacing the reality.
- **Interactive in real time:** This aspect is a constraint that alignment and rendering of objects has to be done in real-time. The appearance depends on users input or changes in the environment.

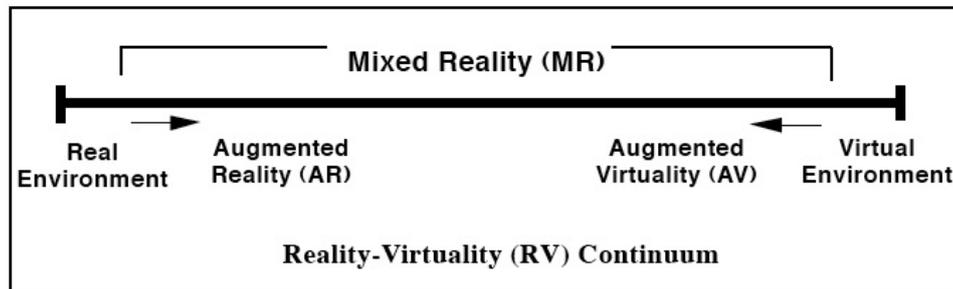


Figure 2.1: Reality-Virtuality (RV) Continuum, Courtesy of Milgrim [30]

- Registers (aligns) real and virtual objects:** Graphical information in the AR environment has a correct spatial alignment relative to the actual surroundings of the user. Like in the rightmost picture of Figure 2.2 the virtual, yellow object must always have the same relation to the book and the can irrespective of the user's motion. This consistent three-dimensional alignment is the basic feature of augmented reality. To achieve such a useful registration, the position of the user's head or respectively the display used in the system has to be determined over time.

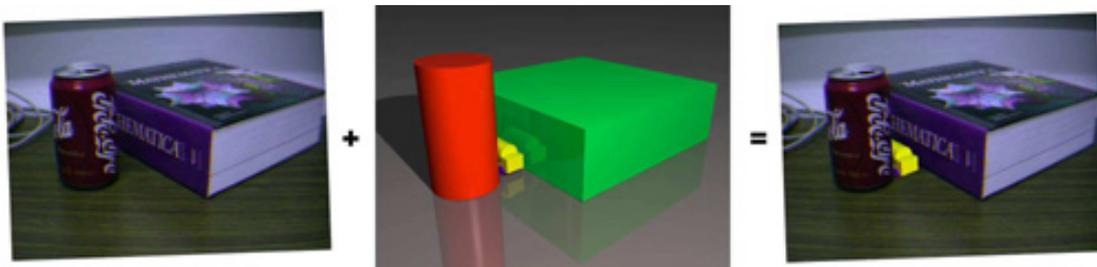


Figure 2.2: Real + Virtual Objects = Combined and aligned Objects (Courtesy of FAR [27])

2.1.2 Tracking

The procedure of continuous estimation of the users position and movement is called tracking. Depending on the captured information the 3D viewing parameters for rendering are synchronized, so that the real and the virtual view are aligned. In the context of using AR for indication of conformal navigational aids there is the need for two different tracking solutions. On the one hand Global Positioning System (GPS) in combination with relative measuring devices like gyroscopes and accelerometers have to be used to get the cars position. While on the other hand the driver's head position has to be tracked for matching these with the 3D viewing parameters. These tracking solutions are not relevant for the work of this thesis but are mentioned since they would be needed for a real-world system integrated into cars.

2.1.3 Displays

Beside tracking, the display technology is another important component of Augmented Reality. Usually AR refers to head-mounted systems in which computer graphics are overlaid onto a live video picture, called video see-through, or projected onto a transparent screen, called optical see-through. Due to the different needs of the addressed application scenarios, a big variety of display solutions have been proposed, for further details about AR displays see [3, 18, 30].

Using Augmented Reality for the extension of the street scenery with conformal (location-fixed) navigation aids refers to a system in which virtual arrows are projected onto optical see-through displays in front of the driver. This thesis focuses on Head-Up Display (HUD) technology used as the optical see-through device. HUDs were pioneered in military aircraft to centralize critical flight data within the pilot's field of vision (See figure 2.3(a)). Later on this innovation was introduced to commercial aircraft to display airspeed, altitude, a horizon line and other important data. HUD technology has already entered the automotive domain, but up to now merely symbolic navigation information or speed-limits are displayed to the driver (See figure 2.3(b)). In comparison to in-car displays, so called Head-Down displays (HDD), Head-Up Displays enable the driver to perceive the presented information without looking inside the cockpit. There are two types of HUD. Fixed HUDs are optical see-through devices attached to a vehicle or to a frame. Determination of the displayed image is depending solely on the vehicles orientation. Whereas the second type, Head-Mounted Displays (HMD) are displays with lenses embedded in a helmet, glasses or visor and the rendered objects depending on the orientation of the user's head. HMD enables the user by turning his head to have a look around in the real environment augmented with virtual objects. Displaying conformal information into the HUD demands for a solution wherewith the rendering depends both on the vehicles orientation and on the position of the driver's head.



Figure 2.3: Head-Up Displays

2.1.4 Rendering

The third basic element for Augmented Reality is real-time rendering. Rendering is the process of generating the image or animation from the model of three dimensional objects. The

model information comprises the geometry and texture of each object. Rendering generates the final appearance of the three dimensional scene and their objects with regard to the viewpoint and the lightning conditions. Finally the rendering procedure computes the two dimensional image out of all these informations from the viewpoint of a simulated camera. Thus rendering is a computation-intensive process. The visual quality depends both on the used mathematical algorithms and and on the available computational resources. While in many applications it is important that the viewer is not able to distinguish between real and virtual objects, in our case virtual objects have to be clearly identifiable. In particular it is important the the driver can determine the navigation aid's location on the street exactly.

Another essential aspect to provide realistic integration of virtual objects into real environment requires that virtual objects behave in a physically plausible manner. This means that they occlude or are occluded by real objects and they cast shadows on other objects. To simulate such constraints, a very detailed description of the real world with all objects would be required. This issue will be discussed in terms of our context in a later chapter 4.

2.2 Human Factors

As already mentioned, the development of new in-vehicle systems requires a careful investigation of human factor issues. This is not only important for their usability for the universal user population, but also to ensure that they are non-hazardous and contribute to driving safety. Maintaining the intention of those systems to make travel more efficient and safer, implies the study of how humans behave physically and psychologically in relation to the provided system within a particular environment. By reasons of humans are neither predictable nor deterministic, development of new approaches is not only engineering work, furthermore it implies an interdisciplinary field of research. Therefore, to provide usable and intuitive route guidance information, knowledge about humans and their mental process of navigation and is demanded. Furthermore conformal indication requires a visual correct placement of route information, so an understanding of visual depth perception is crucial. Therefore this section starts with a survey about driving in general, comprising the main aspects like origin and impact of distraction and furthermore gives an introduction to relevant aspects related to the humans task of navigation. This is followed by an overview about visual depth cues and how human's use them for depth perception. The results are used as fundamentals to consider design aspects for conformal route guidance information.

2.2.1 Driving

To cope with the task of driving it is just more than knowing and applying the rules of the road. Moreover it demands a some level of cognitive effort. Different approaches to categorize the task of driving can be found in literature. Horrey [25] has broken down the primary task of driving into the following three subtasks:

- Vehicle control: Controlling of vehicle speed, acceleration and deceleration and positioning of the vehicle in the own lane is denoted as vehicle control.
- Hazard awareness: This subtask involves the general understanding of the immediate environment, including the detection and identification of obstacles and potential

hazards. Furthermore drivers have to manage the complexity of informations they perceive and react in an adequate manner.

- Navigation: This subtask refers to a higher-order task, selecting, planning, and executing a particular route towards the desired destination.

Driving information has to be perceived by all senses, processed by the brain and transcribed into the next step of interaction. Another approach for categorization is cited by Bubb [10], who subdivided driving in an hierarchical cascade of the concurrent subtasks

- Navigation: Mentioned as the highest level of these tasks, is the process of planning and finding the paths which have to be driven to reach the desired destination.
- Guidance: This subtask is the task of managing the local environment around the vehicle by choosing an adequate maneuver.
- Stabilization: The lowest level of the driving tasks refers to the control activity in order to realize safely the maneuver.

The models proposed by these authors can be used for a more detailed discussion on the impacts of new technologies in cars regarding accidents and driver safety.

Distraction Therefore, the question of additional visual and cognitive stress, and a potential distraction of the driver by the large amount of information, and its complexity becomes predominant in research [34]. Various scientific research has been conducted to measure the amount of distraction as to identify the source of distraction induced by completing tasks in terms of supplementary systems [21, 22, 38]. To get meaningful results for the problem of driver distraction it is essential that study comparison and evaluation of accident statistics can be carried out [34]. For this reason a unique definition of the term is indispensable. Pettitt and Burnett define distraction in terms of four components:

- The difference of distraction and inattention: The key consideration is that distraction can result in inattentive driving, but inattention is not always caused by distraction.
- The recognition that distraction can be internal and external to the vehicle: The internal distraction can be driver initiated or non-driver initiated, whereas the external distraction is in all forms said to be non-driver initiated.
- The distraction can be categorized into four groups: These types are visual, cognitive, biomechanical and auditory, and commonly referred to in literature [34]. The distinction of these types do not have to be mutually exclusive.
- The effect of distraction on the driving task: Denoting a secondary task to be distractive implies that there is a measurable impact on the driving performance.

Another definition is given by Recarte [38], who distinguishes the source of distraction as of endogenous sort, like emotions, stress or daydreams as well as of exogenous sort, like physical stimulus through the five senses. A further definition used by Green [22] is the distinction between eyes-off-of-the-road and mind-off-of-the-road.

Distraction caused by navigation systems In terms of navigation systems two sources for distraction can be phrased.

- First, the visual demand the driver needs to catch provided navigation information, which comprises the head and eye movement towards the display and furthermore the time the driver's eyes need to focal accommodate to see clearly the information indication.
- As second source the cognitive demand can be mentioned. This demand includes the interpretation and transformation of the given navigation information, so that it is mapped to the real world environment.

Head-up displays had been addressed in various research [2, 12, 11, 46] focusing on their ability to enable the drivers peripheral detection of events outside the vehicle while glancing at the display. Further on the focal accommodation time is reduced as the information appears above the engine and the driver does need to adjust the eye's focus to the inside of the car. By reasons that drivers are more effective in the navigation task when using a HUD, as compared to a traditional in-vehicle display, HUDs may be most applicable to situations in which the visual modality is highly loaded and especially for older drivers who experience difficulties in rapidly changing accommodation between near and far objects [16].

Hence, this location for such a display does reduce but does not diminish the visual demand to it's greatest extent. Moreover the cognitive demand is still required. To overcome this limitations, HUDs in combination with Augmented Reality provide a powerful alternative to common navigation systems. Embedding route guidance information direct in the environment, does support the driver in his driving task and minimizes the driver's workload. The driver's visual demand for focal accommodation between the street scenery and provided information is eliminated *and* the driver's workload is reduced, because he does not need to match the supplied route information to his environment.

2.2.2 Navigation

"The more we know," concludes Reginald Golledge [20], "about how humans or other species can navigate, wayfind, sense, record and use spatial information, the more effective will be the building of future guidance systems, and the more natural it will be for human beings to understand and control those systems."

Due to this statement there is a great interest in understanding humans and their task of navigation. Especially in our context of designing conformal route guidance, where no standards are set, great knowledge about wayfinding support is required. So, first aspects related to humans task of navigation will be introduced, followed by an overview about resources and principles for supporting human's wayfinding.

Navigation Several different approaches to define navigation do appear in todays literature [7, 48, 45]. Actually this word is derived from the latin roots *navigare*, which means leading a ship, but over the course of time the usage has been extended to other fields like the aviation, automotive or the computer domain. Navigation is a fundamental human task in physical environments, but as well in synthetic environments. The user is faced with this task, navigating within a virtual world of computer games or navigating the world wide web via the browser are examples. Navigation is the metaphor of determining one's position so as to safely travel to a desired destination. It comprises the tasks of planning and

maneuvering a craft or vehicle from one place to another. To provide efficient movement, the user has to know where he is in relationship to other objects in his surrounding. He needs support for spatial awareness.

Subdividing navigation into travel and way finding is a often cited definition used by Bowman [7]. Travel is the motor component of navigation, the task of performing the action that moves one from a current location to a desired direction or a target location. This, in our context denotes the act of driving a car. Wayfinding is the cognitive process of defining a path through an environment, thereby spatial knowledge has to be used and acquired to built up mental maps.

Another approach is to subdivide driver tasks into a navigation task requiring global awareness and a driving task needing local guidance [45]. Global awareness is the knowledge about the route to the desired destination. Local guidance involves controlling and maneuvering the vehicle with spatial knowledge of the immediate surroundings, which comprises precise estimations about the distance to other cars or obstacles and about the near environment. The critical tasks the driver has to manage are those of control the car's movements, awareness and judgement of where things are and checking whether his forward field of view is congruent to the goals of navigation [48].

Cognitive Maps Performance in human wayfinding activities depends on the use and acquisition of spatial knowledge and the role of cognitive maps [7]. Bowman distinguishes the use and acquisition of spatial knowledge in exploration, search and maneuvering. Exploration means to acquire spatial knowledge, search involves the use of existing and acquisition of new knowledge, whereas maneuvering is termed for small-scaled movements for orientation. Cognitive maps are the mental representation of spatial cognition, which includes acquisition, organization, use, and revision of knowledge about spatial environments. Spatial knowledge consists of different levels of knowledges. One of the most common distinctions in spatial navigation research concerns the difference between landmark, route, and survey knowledge of an environment [47]. Landmark knowledge refers to the memory for objects at fixed locations, like buildings. This cognition serves for orientation within the environment but does not comprise the knowledge about the route. Route knowledge refers to the memory for procedural linking of known landmarks. This includes knowing about paths or distances between fixed landmarks or their order. Survey knowledge is the abstraction of specific sequences of landmarks or routes into another representation model. Path segments can be substituted by the street names and estimations between unseen places are possible. So survey knowledge is the highest level of spatial knowledge and takes longest for acquisition. The usage and acquisition of spatial knowledge is influenced by such factors as the reference frame, and the travel technique [48]. Egocentric frame of reference refers to the human's own perspective, whereas exocentric refers to a top-down, map- or world-based perspective, (see picture 2.4). The transition of landmark knowledge, which concerns an egocentric frame of reference, to survey knowledge, which concerns an exocentric frame of reference is denoted as building cognitive maps. The challenge to navigate is that each of these knowledge presentations are expressed in different frames of reference. Orientation is highly egocentric referenced in terms of the forward field of view. The world is defined in terms of left, right and near, far. Whereas the problem of defining the navigation goal refers to more world referenced orientation, and could be expressed in terms like "north of the city"

or “on the other side of the river”. The navigational knowledge of finding a path through the environment depends upon the other two states of references. The knowledge of north must be defined in terms of the human’s egocentric view, so that he knows which way to go next. Summarizing, the essential part of wayfinding is the development and use of a cognitive map, which is strongly connected to frame of reference. Integrating landmarks and the spatial relation along them, make up the internal presentation of the environment and are the basis of route knowledge. The linking of route knowledge results in survey knowledge.

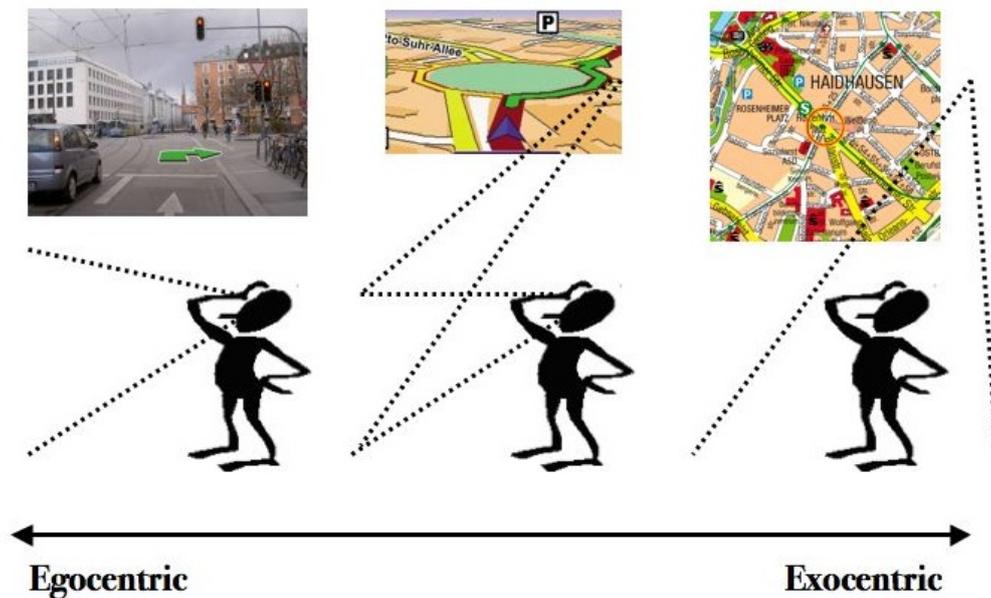


Figure 2.4: Frames of References

2.2.3 Conformal Navigation Indication

Presenting conformal route guidance aids, so that these appear to be part of the street scenery requires a visually and spatially correct indication. This means navigational arrows have to be displayed in their exact depth, so that the driver has an understanding of the aid’s position within the three-dimensional world. The navigation information has to be displayed, seemingly aligned on the street and thus pretending to be like a real object integrated in the environment. Therefore understanding what depth cues the human visual system uses to get spatial information is crucial. This section gives an brief overview about these cues and their importance for the requirements of the visual display. In the second part of this section important aspects related to information indication in HUDs and their relevance to the task of driving will be mentioned.

2.2.3.1 Depth Perception of Conformal Route Information

In natural vision, perceiving objects in their correct depth perception, which means to accurately determine the size and location of an object, is based upon a variety of depth cues [18, 29]. In real world depth cues do interfere with each other and resulting in an accurate perception of depth [19]. Binocular, oculomotor, monocular cues and motion parallax are the four categories visual depth cues can be broken up to [7].

Oculomotor cues:

These cues refer to the muscular tension of the human's visual system and for that reason are called oculomotor. Accommodation, is the cue to adjust the eye's focus on different distances by contracting and relaxing ciliary muscles. After a while humans learn the relation between distance and focusing and can use accommodation as an indicator for distance estimation. Convergence is also an oculomotor cue which is required when objects are brought close to the observer. Then the two eyes converge to focus on the object.

Binocular cues:

Retinal disparity refers to the binocular cues where both eye's are used for and is the effect that two different images of the world are perceived by each eye. The information derived from these two different images can be processed by the brain to give the opportunity for distance interpretation.

Motion parallax:

Motion parallax is a depth cue that results from the viewer's motion. Objects that are closer to the viewer move farther across the field of view than objects do that are in the distance.

Monocular cues: Monocular cues can be perceived with just one eye and are strong cues at all distances. These cues refer to the knowledge humans have about the objects in relation to the world. Perceived information is compared with certain memorized visual rules and processed for distance interpretations. This category of cues can be used for depth estimation within static images, for that reason these are also often mentioned as pictorially cues. Different listings can be found in literature, but comprising almost the same cues. For example, Wickens [49] mentions the following monocular cues for depth perception:

- Linear perspective: Two converging lines appear to be parallel and receding in depth.
- Interposition: This is when one object obscures another, the object that is partially obstructed appears more distant.
- Light and shadow: An objects' shadow when lighted provides some clues about the objects' orientation relative to us and its three-dimensional shape.
- Relative Size: Two objects have the same size, but one appears smaller, than this is more distant.
- Textural gradients: Textures grow finer at a greater distance.
- Aerial perspective: Due to light scattering by the atmosphere, objects that are a great distance away look hazier.
- Proximity-luminance covariance: This cue is closely related to textural gradients in that the closer an object is the brighter it appears. Therefore a reduction in illumination and intensity are assumed to be further away.

- Relative motion parallax: When we move relative to a three-dimensional picture the objects that are closer appear to have greater relative motion to those that are further away.

Depending on the distance of objects from the user, relative effectiveness of the cues change. Accommodation, convergence and retinal disparity (binocular and oculomotor) cues are strongest at a close distance. Different statements about their range of effectiveness can be found in literature. Goldstein [19] and Gupta [24] state a distance less than 3 meters [24, 19], whereas Bowman [7] cites the distance limitation of less than 10 meters. Monocular cues, however, are strong cues at all distances.

Providing depth cues for virtual objects is always subject to technological limitations. Usually only a small subset of available depth cues can be fully implemented and the other ones are missing. But more uncertain is the outcome in situations where depth cues conflict [18]. Like if route information would be displayed directly in front of the driver although the indication shall provide the illusion of being placed further away, two depth cues would be in conflict and perception would be distorted. Due to this, an approach is needed to overcome the limitation, that the driver could be irritated by different depth cues. The solution providing a sense of depth perception for virtual navigational arrows implies that the image for displaying has to be placed in a distance where binocular or oculomotor cues do not take an effect or at least are minimized insofar as distance interpretation is depending solely on monocular cues.

Then accommodation and retinal disparity can not interfere with the designated goal for displaying information in distance.

However, an increasing amount of depth cues do enhance perceptibility in distance. Presentation of route guidance information with their exact depth in terms of the other mentioned cues, can be solved by the rendering process, but have to be taken into consideration when designing such conformal indication. Further details for this purpose will be given in chapter 4.

2.2.3.2 Important Aspects referring Conformal Route Information

In the aviation domain HUD technology is integrated as a standard, but despite significant aviation safety benefits due to this technology a number of accidents have shown that their use does not come without costs [36]. The section exposes that as a consequence of new technologies some distraction effects can arise. Within this section psychological phenomena like perceptual tunneling, cognitive capture, change blindness will be explained in matters of their interference to the task of driving. Though, in comparison to aviation where pilots are trained in usage with new technologies, these effects could become more hazardous. Additionally, vehicle-based HUDs will be used by people with different perceptual/ cognitive capabilities and within an environment where there is a complex, continually changing visual scene [11]. All these have to be taken into account by the development of all in-vehicle systems, but because of the dominant role of information indication within in the HUD, in our context they have to be considered with much more caution.

Information Overload Information overload refers to the state having too much information at the same time, so the user is not able to perceive the important information. For instance, Head-Up displays enable the indication of significant information, such as speed limits or safe distance information, directly in the driver's field of vision (see Figure 2.5). In matters of keeping the driver informed, a large amount of diverse informational signs can be displayed, but the effect of information overload should thereby stay in mind.



Figure 2.5: Information Overload in HUD

Change Blindness Change blindness refers to a failure detecting what should be an obvious change [40]. In human-computer interaction it occurs when more than one change is happening at a display at the same time or the user's attention is distracted. The user has to memorize the state before the change and in comparison has to detect the new state to recognize that a change already had happened. An attempt to reduce the possibility to miss an important change is to make changes explicit. Within the task of driving, missing the change of navigation information could be irritating in some kind of distracting for the driver. But missing important changes outside in the street scenery is much more crucial and could lead to serious consequences.

Perceptual Tunneling Beside information overload, displaying information, especially animated warning schemes into a car's HUD, can lead to perceptual tunneling. Furthermore, if the provided navigation information is displayed in too dominant a way, this phenomenon is first being recognized in aviation and refers to a state where the human is focused on a specific stimulus and neglects to pay attention to other important tasks or information, like in this context driving or the traffic. The human is only visually attracted by a specific stimulus, but does not spend cognitive load on the stimulus; he is only staring at something without thinking about it. This effect is known in everyday situations like, for example, being with friends in a bar where a TV is turned on and one has to stare at the TV without recognizing

what he is looking at. But the visual attraction can easily change to a cognitive attraction and thereby lead to the next mentioned phenomenon cognitive capture. [6]

Cognitive Capture Focused attention refers to the ability to process only the necessary information and filters out that which is unnecessary [36]. This attention mode can lead to cognitive capture which refers to the situation where the driver may be totally "lost in thought" and thereby could lead to loss of situational awareness [42]. This effect is known in everyday situations like for example a person in a cinema is looking out for a free seat and is thereof lost in thought about this task, so that he does not see a friend who is waving to him. Whereby in this case perceptual tunneling does not cause important consequences whereas in time-critical tasks this can cause hazardous effects, like increasing the risk of a crash.

Conformal navigation systems gain more capabilities and thereby enable more intuitive navigation indication and reduce glance-away time in comparison to standard navigation systems. New technologies on the one hand promising new possibilities for information indication and especially for time-critical tasks, but on the other hand as a consequence no experience in terms of psychological aspects have been made and no standards are set. So great care has to be taken by designing conformal navigation systems. The design is an interdisciplinary field of research, because not only technical aspects as well the physical and the psychological situation of the user have to be taken into account. Therefore knowledge in perception, cognition, human factors, ethnography, graphic design and others is very important. Further on, for the evaluation about new technologies in terms of their cognitive and visual demand usability tests are indispensable.

2.3 Empirical Evaluation

Enabling conformal indication, so that route guidance information is seemingly integrated into the street scenery, to make travel more efficient and safer, seems to be a promising solution. However even the most careful and well-defined design can fail the intention to enhance driving safety and comfort. Thus, usability studies have to show the benefits and drawbacks of the different Augmented Reality visualizations. Especially in our context of driving, where underestimated negative implications could be the cause of crashes. The importance of side effect estimations postulates the accurate interpretation of the experiment results. So, this section explains the important concepts for an appropriate empirical evaluation. It rests upon Rash, Bortz and Broy [37, 5, 9].

2.3.1 Hypotheses

A hypothesis is a prediction or proposed solution to a problem. It is based on prior knowledge or information gathered and can be seen as an guess about the outcome of an experiment. Framing a hypothesis is the art of phrasing questions in a way they can be evaluated and is therefore the initial phase of the verification of theories. Ascertained data within usability studies will be analyzed statistically and therewith give evidence about the hypothesis. First of all the alternative hypothesis (H1) is set up and based on it, the exact opposite

(null) hypothesis (H0) is formulated. The likelihoods of H1 and H2 are compared by a statistical hypothesis test. Usually the alternative hypothesis is the possibility that there is a difference between the observed effects and the null hypothesis is the rival possibility that within the systems there is no difference in terms of the independent variables. Further on directional alternative hypothesis are used to show which of the compared systems is preferred whereas non-directional alternative hypothesis merely say that there is a difference between the systems.

Usability studies can be executed with the entire population. For that reason a random sample is chosen. The test results of this sample shall give an universal predication about the population. On the base of the results, decisions have to be made which of the both hypotheses has to be rejected and which one has to be accepted. If the prediction was correct, then usually the null hypothesis will be rejected and the alternative accepted. If the original prediction was not supported in the data, then the null hypothesis will be accepted and the alternative rejected. But beside a correct decision on the basis of test results it is still possible that actually it came to a wrong decision. All possibilities are illustrated in Fig.2.1.

		In population	
		H0	H1
In sample	H0	right decision	Type II-error
	H1	Type I-error	right decision

Table 2.1: Type I and Type II error

Type I error is the error of rejecting a null hypothesis when it is actually true. In other words, it occurs when we are observing a difference when in truth there is none. Type II error is the error of failing to reject a null hypothesis when the alternative hypothesis is the true state of nature. In other words, this is the error of failing to observe a difference when in truth there is one.

To reduce the probability of type I error statistics include decision rules for accepting or rejecting the null hypothesis. These decision rules are described with reference to a computed value called P-value. The P-value gives information about the probability with which the test data of the sample cannot be seen as representatives for the population. The probability of committing a Type I error is called the significance level. In this study 5 % is defined as the level of significance. If the P-value is less than the significance level 5 %, we denote the result as significant and reject the null hypothesis. A threshold value for the probability of committing a type II error cannot be defined clearly. The probability of a type II error can be guessed with help of the type I error. However p must be greater than 0.25 to accept the null hypothesis.

2.3.2 Evaluation

To enable reasonable evaluation and interpretation of data gathered from an experimental study, it is fundamental to prepare and describe the collected raw data in a statistically way. This comprises the collection, the classification, summarization and the presentation of these data. Descriptive Statistics are used to describe the basic features of the data and to provide

simple summaries about the sample and the measures. In terms of descriptive statistics, central tendency and statistical variability are the two essential objectives for the summary. Measures of central tendency are the arithmetic mean, the median, or the mode of a data unit and show how different units seem similar. The most common measures of variability for quantitative data are the variance and the standard deviation.

2.3.2.1 Analysis of Variance

The main goal of many studies is to contrast data from different groups of subjects. Measurements are often analysed by the t-test, a method which assumes that the data in the different groups come from populations where the sample variables have a normal distribution and the same variances or standard deviations. While the t-test is used to compare two different groups, the one-way analysis of variance (also called ANOVA [5]) is the correct approach if the mean value of more than two groups have to be compared, because otherwise the type I error rate would rise with the number of performed tests.

The procedure of ANOVA is based on the same assumptions as the t-test and thus can be seen as a generalization of the latter. The basis for both test is to phrase the question in terms of a null hypothesis, essentially that the groups are equal, and then to test whether that can be accepted within a certain probability. The assumption of equality between the groups implies, in contrast to the t-test, that only non-directional hypothesis are possible. Evaluation whether there is evidence that the means of the populations differ means to compare the groups in a statistically way. The basic principle of the one-way ANOVA is to separate the total variability in the outcome of the test into two parts, in variability within groups and in variability between groups.

Thus the variability of the individual data values is partitioned into components which are corresponding to within and between group variation. Decision, whether there is a difference between the groups or not, are made by comparing the means of the groups variance. In the following the different variances and their use for hypotheses testing will be explained.

Variance Variance is a measure of the spread of the values in a distribution. The larger the variance, the larger the distance of the individual cases from the group mean. The overall variance indicates the variation off all measured values, without subdividing the values in terms of different test conditions. The overall variance can be partitioned into two components in terms of the two causes which are responsible for the measured values. Firstly, the methodical influences, which are attributed to the manipulation used within the test. These artificial influences are deliberately used to produce the differences between the groups, to effect the treatment and as are consequence thereof the appropriate variance is termed as the effect variance or treatment variance. Secondly, in contrast to the treatment effect, the unsystematic influences are these who were neither caused intentional nor can these be covered systematically and in consequence the corresponding variance is called error variance. After the experiment it is relevant which of the artificial, experimental intended manipulation influenced the measurements and to which extend. For this purpose the treatment effect in proportion to the error is used for estimations.

Variation within groups The first step is to calculate the error variance, which is the average variance within one treatment or group, by comparing the mean deviation of each value with the mean of the group. This variance is called the within-group-variance. The expected value of this error variance is corresponding to measured variance of the population.

Variation between groups In contrast to the error variance, there is not a single value with which the effect variance could be estimated. To estimate the influence of the treatment variation the mean values of the groups are used. The variance of the groups' mean is denoted to the between-group-variance. Unfortunately the between-group-variance is invariably coupled with the within-group-variance, because the unsystematic effects also influenced the mean which was used for between-group-variance calculation.

F-fraction Though to get information about the treatment's effect the f-fraction is used to compare the between-group-variance and the within-group-variance (see 2.6). The expected value of both variances only differs from the effect the test is interested in. If the experiment is affected by the treatment not at all or hardly, then the between-group-variance, which is calculated by the sum of effect and error variance, is equal to the error variance and the fraction's result is 1. But if the treatment does affect the experiment, then the between-group-variance is greater than the error variance and the fraction's result is greater than 1 (see 2.6). Thus, if the f-ratio is equal to 1, then the effect variance was equal to 0 and if the f-ratio is greater than 1 then the effect variance was greater than 0.

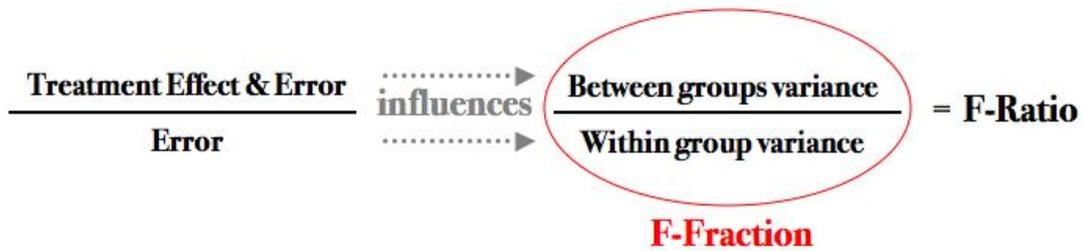


Figure 2.6: ANOVA: F-fraction

F-ratio This f-ratio is a random variable with $F_{k-1, n-k}$ distribution, in which k is the amount of treatments or groups and n is the amount of measured values. These indices are denoted as the degrees of freedom. The f-distribution with its degrees of freedom gives information about the probability, with which a certain f-ratio does arise when the null hypothesis is true. Is the probability very low than the appearance of such f-ratio improbably. But does such a ratio appear then this is extremely strong evidence against the null hypothesis.

Probability of the f-ratio If the probability of a f-ration ($p(\text{f-ratio})$) is less than the level of significance level, which is defined before, the result is denoted as significant and the null

hypothesis will be rejected. Thus the f-distribution and their values can be used for verifying significance of the measured results. To get the probability value of the f-distribution for given degrees of freedom, the Fisher-table can be consulted or it can be estimated by using an effect size measure, like the partial Eta squared.

Verification of the significance gives evidence whether the alternative hypotheses should be accepted and in consequence that there is a difference between the groups, but it cannot indicate which of the groups differ.

2.3.2.2 Post-Hoc-Analysis

To investigate which of the groups caused the rejection of the null hypothesis post-hoc or multiple comparison tests can be used. Post-Hoc tests examine or compare more than one pair of means simultaneously. The Scheffe post-hoc test is one of the variety of tests and tests all pairs for differences between means and all possible combinations of means. This Scheffe post-hoc test helps to compensate for threadbare significant results that occur with multiple comparisons and is according to that known to be conservative.

3 Related Work

Similar Research Projects using Augmented Reality in Cars and/or for Route Guidance

This chapter introduces other research projects which are related to this work. The first part gives a survey about approaches for the integration of Augmented Reality in the automotive domain, this comprises video-based navigation, driving assistance approaches and head-up technology. The second part focuses on research areas for using Augmented Reality for wayfinding in general. The last part addresses perceptual issues in Augmented Reality.

3.1 Augmented Reality in Cars

Video-based Augmented Reality navigation Siemens AG in cooperation with the Johannes Kepler University Linz and Ars Electronica Future Lab developed a new visualization concept for navigation systems, where the annotation of the route is superimposed on a live-stream video showing the road ahead on the navigation display [32, 31]. Within their prototypical implementation they showed the video in an in-vehicle display where the route is marked in a translucent color, see figure 3.1. This technical approach on the one hand does not reduce the glance-away problem but on the other hand is advantageous in terms of being independent to the daylight conditions. Unfortunately no usability studies have been performed to give more evidence about the potential benefits and limitations.



(a) Correct navigation indication

(b) Correct navigation indication

Figure 3.1: Video-based navigation (Courtesy of [31])

A similar approach has been developed by Wu et al. at the Carnegie Mellon University in cooperation with General Motors. They provided a multimedia system for route planning

and video-based navigation [50]. The driver has the possibility for route sharing in the trip planning process and the driving instructions are given by an live-video image overlaid with navigational arrows and with additional synthesized voice instructions. Two different designs for route guidance information were tested, where perspective arrows resulted as the preferred one over the icon-based navigational arrows. They tested their system in indoor and outdoor context, see figure 3.2. They mentioned that video-based navigation reduces the cognitive load in some cases, but on the other hand such approach has also limitations: In the outdoor context the cognitive load from watching the video of a night route could be higher than reading a map, due to all the hidden details because of the low-light conditions and the size of the screen.

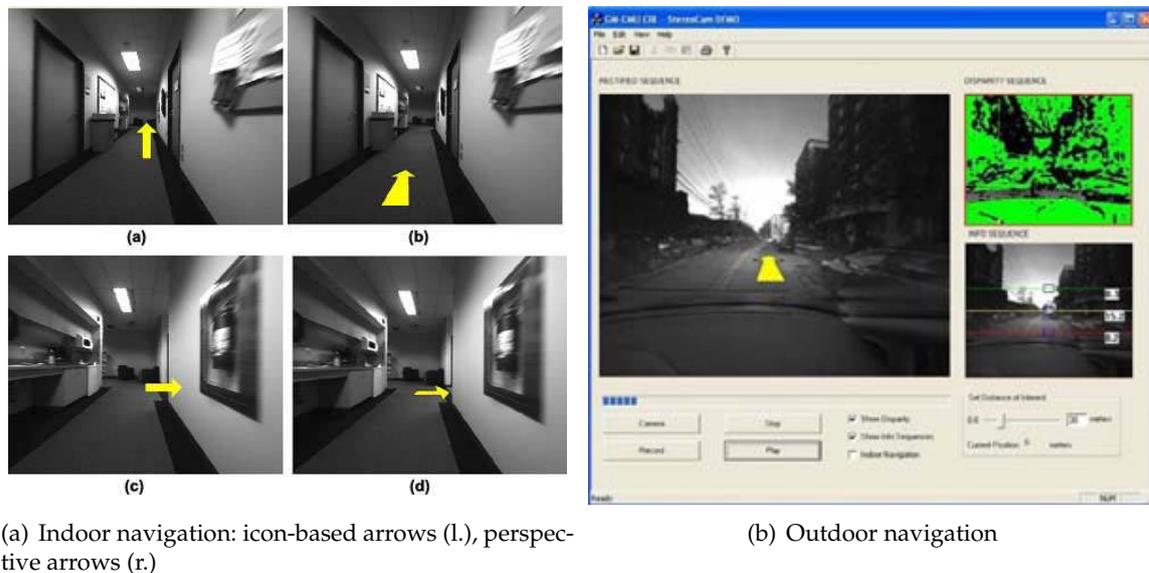


Figure 3.2: Video-based navigation (Courtesy of [50])

Augmented Reality for driving assistance in cars Tönnis et al. investigated the potential of integrating Augmented Reality solutions into the car to enhance the safety by guiding the driver's attention to an imminent danger somewhere around the car [43]. Within his work he compared an AR-based presentation scheme (see figure 3.3(a)) with a bird's eye schematic map (see figure 3.3(b)) for indicating the direction towards the danger location. The experiment was performed in a driving simulator where the presentation schemes were displayed into a head-up display. Furthermore both were tested in combination with an acoustic signal to give further information regarding the position and direction of imminent danger. The result of the experiment gave evidence that the AR-based indication resulted in both cases, with and without sound support, in better performance than the bird's eye schematic map.

Further research of Tönnis et al. [44] was the evaluation of a visual longitudinal and lateral driving assistance in the head-up display of cars. Two AR-indication schemes were developed to enhance driver's safety by displaying where the car is heading to and in which dis-

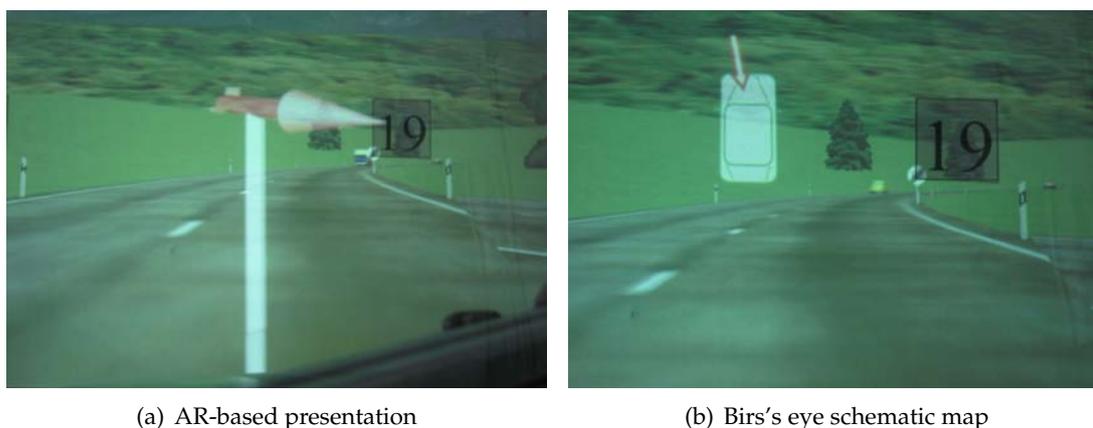


Figure 3.3: Visualization for guiding to imminent danger (Courtesy of [43])

tance the car would stop in case he has do an emergency stop. The one presentation scheme indicates the breaking distance by a virtual bar on the road (see figure 3.4(a)), while the other scheme indicates a pipe between the car and the bar (see figure 3.4(b)). Both schemes were tested in a driving simulator and the experiment showed that such AR-indication supports driving performance and that it does not increase mental workload. The bar presentation scheme was preferred to the drive-path presentation scheme in terms of matching the general design principles to keep information as minimal as possible.

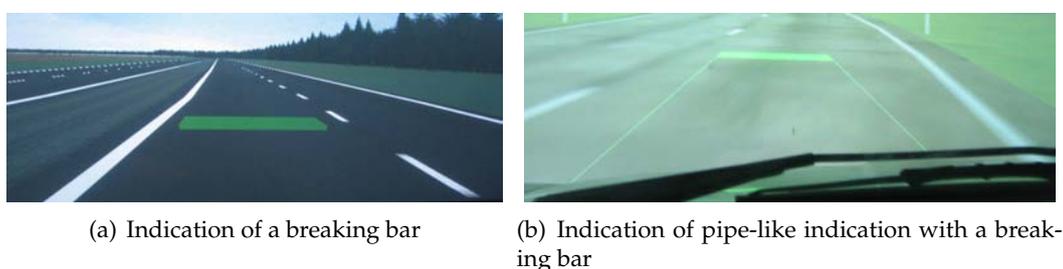


Figure 3.4: Visual longitudinal and lateral driving assistance (Courtesy of [44])

Both research gave evidence that Augmented Reality based techniques as novel approach for user interaction do enhance driver's safety.

Conformal Head-Up Technology Sato et al. [39] implemented a visual navigation system where the whole windshield is used as a head-up display. Projected into the windshield the system shows navigation direction and distance to a destination as a visual sign. The system enables a solution for high-luminance indication, but does not take care of the accommodation problem. The driver has to adjust his focus to the close range to perceive the provided information.

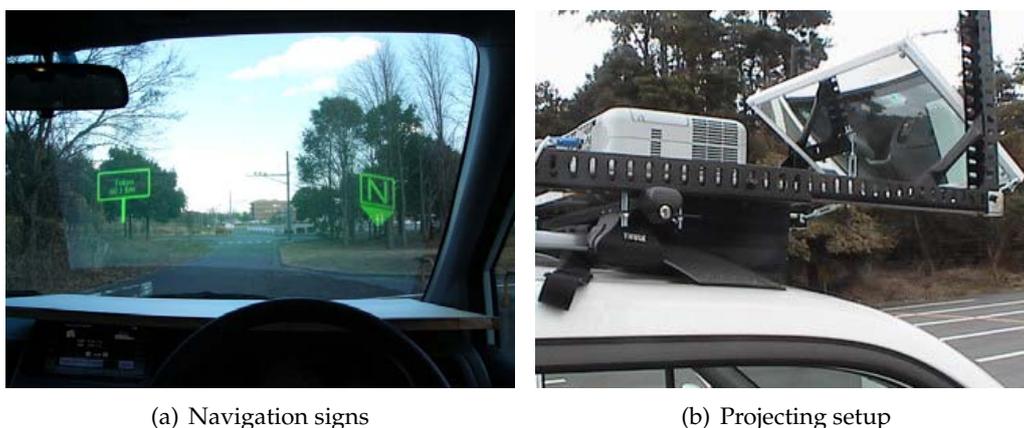


Figure 3.5: Windshield head-up display (Courtesy of [39])

3.2 Augmented Reality for Route Guidance

Chittaro and Burigat [17] performed an experimental evaluation comparing three different ways of providing navigation guidance by combining visual and audio directions on a mobile device during guided city tours. The three considered visual solutions, a traditional map-based solution, an alternation of a map and photographs of the area, an alternation of large arrows and photographs were tested in combination with audio guidance. The results showed that the combination of photographs or arrows with maps provide a better navigation support than when using the map alone. This gives evidence providing egocentric conformal route guidance, like in our approach, results in better performance.

3.3 Perceptual Issues in Augmented Reality

Gupta [24] studied the effects of context-switch, object distance, and focus depth on human performance in Augmented Reality. The experimental task for the study required the user to repeatedly switch eye focus between a virtual text and a real-world text. A monocular see-through head-mounted display was used within his research. The results of his empirical evaluation revealed that switching between real and virtual information becomes difficult when information is displayed at optical infinity. Furthermore he mentioned that focus depth has no impact on task performance, but if the virtual and the real information are at the same distance to the user performance was better. These results gave a fruitful insight to the perceptual issues in terms of AR, but cannot be transferred to our problem without revision, because the task within this experiment was reading a text and not identifying the correct placement of virtual objects within the real world.

Drascic and Milgram examined limitations of Mixed Reality systems in terms of their capability of accurately displaying relevant depth cues. They identified and discussed eighteen perceptual issues that pertain to Mixed Reality in general, and Augmented Reality in particular [18]. Within their work they introduced to the effect of misleading or conflicting

depth cues. All these perceptual issues gave a valuable insight to the problems which have to be considered when designing AR-systems where depth cues are crucial. Being aware about these limitations helps for designing around the weakness of these perceptual issues. However, providing accurate depth cues for displaying information within a HUD are not mentioned, thus further research for identifying these limitations have to be done.

Bergmeier researched for a method for conformal visualization of driver assistance information suitable for the automotive domain [4]. He focused his attention to a visualization approach for displaying three-dimensional information in large distance (10m - 100 m) by using a HUD. His approach based on minimizing the effectiveness of binocular or oculomotor cues by displaying the image in a large distance where providing a sense of depth is depending solely on monocular cues, see figure 3.6. His results revealed that the desired effect can be achieved by placing the image plane in a distance of about 50 meters. The results of his work were published at the final stage of this thesis and as consequence thereof could not taken into account.

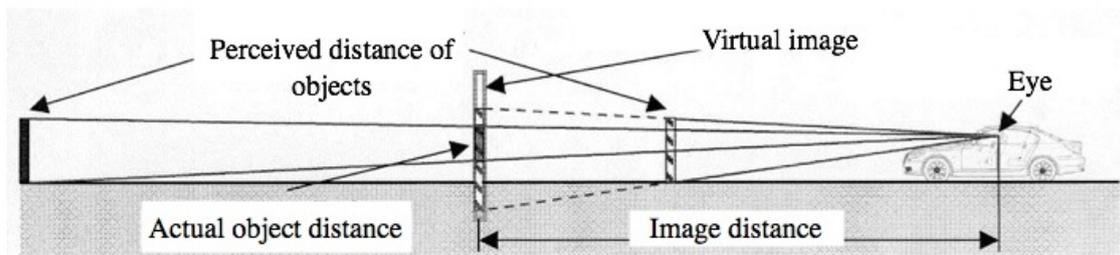


Figure 3.6: Conformal visualization (Courtesy of [4])

4 Design Concepts

Contemplation of Design Concepts for Route Guidance Information

In this chapter we identify and discuss key questions related to the design of conformal navigation aids. Sustaining the intention of reducing the driver's distraction and the cognitive workload requires the consideration of the following three main key issues.

Intuitiveness This means route guidance information must be designed efficient, easy to learn and satisfying, which means navigational aids have to be as natural and easily understandable as possible. Therefore common metaphors, which are easily understandable mental models that allow the user to apply everyday knowledge in the virtual environment [7], have to be identified and integrated in the design development.

Perception of depth Location fixed schemes refer to the indication of placing the wayfinding aids direct on the maneuvering point within the environment. To enable the driver to identify the exact position of the navigation aid, conformal indication requires that sufficient information is provided for depth perception. The importance of this aspect has already been explained in the previous section 2.2.3 and therefore special emphasize is given to this aspects as well.

Perceptibility in distance As location fixed indications eliminate the need to transform the route information to the surrounding, they bear the risk of late detection. Furthermore in situations, where the maneuvering point is too afar to be visible or because other reasons out of sight, there is a need for an indication of the path to the specific maneuvering point. Thus, besides the contemplation about effective location fixed indication, this chapter comprises a collection of ideas about presentation concepts for pathway indication to the location fixed information.

With this three fundamental points in mind, criteria for designing conformal presentation schemes are discussed. Partly these are well known concepts adapted to our problem domain and on the other hand this are own thoughts. It starts with general considerations, followed by design schemes classified by their location: Location fixed, car fixed and hybrid.

4.1 General Considerations

Considerations concerning all visualization schemes will be stated introductory. The existence of geographical dissimilarities has to be mentioned here, but some design considera-

tions like the color coding meet solely the European needs. Due to this, design issues will have to be matched to regional differences.

4.1.1 Color and Contrast

Color In terms of using colors, within human factors guideline [33] is cited, familiar color coding should be used to avoid confusion and colors should be used consistently. The effect of color on human behavior and sensation is a controversial issue. Some have attempted to assign colors to particular human emotions, but this meaning has not been supported by scientific studies. People do respond to different colors in different ways, and these responses take place on a subconscious, emotional level. But in which way the colors influence humans varies with time, place and culture. And even one color may imply different psychological functions at the same place for the same culture. Although some approaches to imply a certain message by the use of colors do exist, shown in Figure 4.1. In our culture, in the context of traffic the appliance of color red for example symbolize danger or interdiction. Yellow and orange are said to attract humans attention and in combination with the contrast color black they shall imply warning information. These colors are perceptible in distance and claim attention. Blue has a calm impact on the sense and with the contrast color white it serves to transfer the meaning of information. Whereas green is suggestive of safety because of the calming sensation. Due to this common color coding, at first sight the suggested color could be blue, because of it's common meaning to transfer information, but could cause problems because the contrast to the background is too slight. So, the second sight emphasizes the color orange by reasons of the perceptibility in distance and the implied warning information.



Figure 4.1: The use of colors within traffic signs

By the use of colors, displaying information into the HUD other important aspects have to be considered as well. When displaying information directly into the car's windshield Sato [39] ascertained, that the windshield material cuts a certain range of light wave, which results in fainting of all colors except green. However, this is depending on the windshields material, so the effect of each glass has to be proofed. A survey of our system setup, where a plane glass was used as a HUD, showed that no difference between the colors was perceptible. Further research has to be done to validate color perceptibility dependent on weather and lighting situations and to identify cognition limitations.

Contrast Different street conditions claim for a solution where provided route information is clearly recognizable in all cases. Achieving a contrast to different gray colors of the street background a solution from the desktop environment could be adapted. The mousepointer

is recognizable independent to the background, because a black color is used surrounded by a white boundary 4.2(a) or vice versa a white arrow is surrounded by a black boundary, see figure 4.2(b). Surrounding the navigational arrow with a white boundary, does enhance the contrast, like in figure 4.2(d), the arrow is better visible in both areas, in the bright and the darker part of the street.



(a) Mousepointer: Black arrow with white boarder

(b) Mousepointer: White arrow with black boarder



(c) Navigation arrow without boundary

(d) Navigation arrow with boundary

Figure 4.2: The use of boundary for contrast

4.1.2 Depth Perception

Providing depth cues for virtual objects is always subject to technological limitations, only a small subset of available depth cues can be fully implemented and the other ones are missing. Further details about these limitation was given in the section 2.2.3. However, an increasing amount of depth cues do enhance perceptibility in distance.

Due to this, supporting depth perception can be solved by the rendering process to some extent. Following effects can be used to enhance depth perception.

Light and Shadow Shadows and lightning play an important role to support the driver determining depth and orientation. An objects shadow when lighted provides some clues about the objects orientation relative to us and its three-dimensional shape. Shadows are

important to estimate the objects location by determining how far an object is from adjacent surface, see figure 4.3.

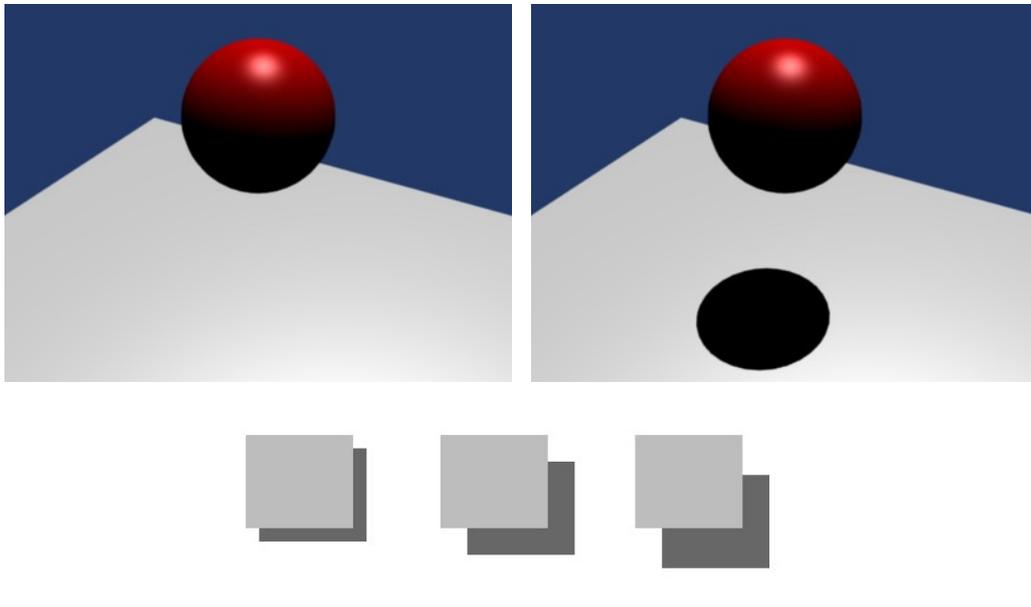


Figure 4.3: The use of shadow for depth perception

Unfortunately, providing shadows on the ground for depth cue is restricted on account of using a HUD. One can not display black color in a HUD as black is seen as transparent in a see-through display. Nonetheless, the shadow and lighting on the object itself provide some clues to recognize the objects' orientation and its three-dimensional shape.

Occlusion Beside this another essential challenge to provide realistic integration of virtual objects into the environment requires that all objects are arranged in physically correct manner. This means that virtual objects occlude or are occluded by real objects, which is also called interposition or interruption cue. Occlusion is denoted to be the strongest monocular cue. To simulate such constraints, a very detailed description of the real world would be required, but up to now no solution therefor exists. But even if there is a solution for displaying correct interposition of objects and street scenery, another problem arise: For example if there is leading traffic the arrow cannot be seen until the leading car has left the position. Thus presenting navigation information without correct occlusion results in a reversed depth cue perception which is irritating and in some kind distractive for the driver (see 4.4). An approach could be to display the navigation arrow while "hidden" from a leading car or house in dashed wireframed manner. Such visualization for occluded objects are used within engineering drawings. So, this visualization could be an understandable metaphor for occlusion indication, but with the addition of increasing the locating problem.

Furthermore, some areas of the surrounding field are occluded, therefore route guidance information should always be displayed semi-transparent. Whether the depth perception and the occlusion problem can be managed by the driver without distraction has to be validated within further research.



Figure 4.4: Navigation arrows (Courtesy of FAR [27])

Relative Size Retinal image size allow to judge distance based on past and present experience and familiarity with similar objects. As the car comes closer to the navigational arrow, the retinal image of the arrow becomes bigger and bigger. Based on the experience the interpretation is that if the arrow is getting bigger it comes closer and if it becomes minor it must be more distant to the driver. This is referred to as size constancy. A retinal image of a small arrow is also interpreted as a distant arrow. Due to this, conformal indication postulates displaying route information in it's consequent size. Approaches to enhance perceptibility of distant information by increasing the size in distance are by reasons of depth perception inexpedient.

Linear Perspektive When objects of known distance subtend a smaller and smaller angle, it is interpreted as being further away. Parallel lines converge with increasing distance such as roads, railway lines, electric wires, etc. Therefore to sustain the exact depth perception, navigational arrows have to be projected in their correct perspective, which means aligned onto the street. Visualization approaches to enhance perceptibility of distant information by displaying information more "up-standing" are inexpedient as well.

4.2 Location Fixed Schemes

Location fixed schemes refer to the indication of placing the wayfinding aids directly on the maneuvering point within the environment. Such indication on it's own is a promising solution to provide local guidance if the driver is in proximity but the driver has to be guided to the visible range of the maneuvering points. This either can be done through symbolic indication or by using one of the approaches mentioned in the next sections.

4.2.1 Conformal Arrows

An arrows is the most common graphical symbol used for pointing or direction indication. The arrow's shape can be in it's simplest form a line segment (shaft) with an triangle (head) fixed on one end or can be design in a more complex form.

Designing conformal arrows for the automotive domain is twofold, on the one hand design guidelines for in-vehicle navigation systems [33], recommend using a very simple form, whereas the enhancement for depth perception requires a more complex solution. The general shape of the arrows is based on the German lane markings for direction information on the streets [1], see left picture of figure 4.5. But these shapes are design perspective per se, so displaying them aligned on the street and therewith in additional perspective view would result in an unrecognizable indication. Thus, firstly the perspective form has been changed to orthogonal perspective, see right top picture of figure 4.5. Further on, some more changes were made for enhancing perceptibility, because aligned and as result perspective arrows are perceived minimized in length and appear very different than with a bird's eye view, see figure 4.5 on the right side below.

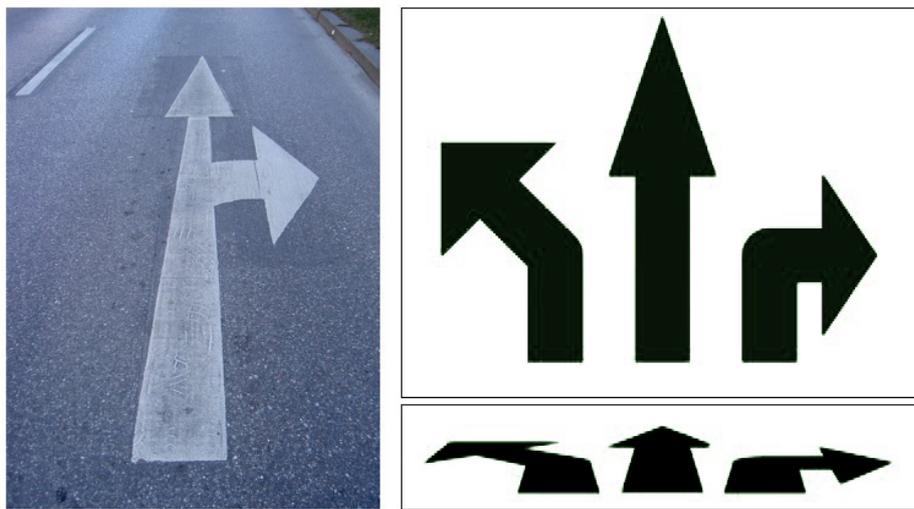


Figure 4.5: Left:Lane marking; Right top:Bird's eye view, Right below:Perspective view

Finding the best solution is a difficult task. A lot of considerations can be made in advance, but implemented ideas result in very different perception like expected in theory. Solely modification of the arrow's head, by changing the proportion of triangle appear in a manner of pointing in a slightly different angle, like it is shown in the figure 4.6. The two arrows differ only in the head's shape and both a pointing in an angle of 45 degrees, but their direction is perceived different. Alternatives of modifications had been evaluated in a pilot survey.

In terms of improving depth perception an approach was of the extension of the arrow's shape to the third dimension. Three-diminsional arrows were designed with a height of 10 cm at most to prevent the potential impression that the arrow could be perceived as an barrier for the driver. Some different ideas had been implemented and revised in a pilot survey during the design phase and the following three different variants had been selected for further evaluation, see figure 4.7.

Other schemes had been implemented and tested in terms of rejection, revision or acceptance as well. For example, implemented arrow visualizations without a bended shaft do most closely correspond to the simple design, recommended within guidelines, but are difficult in recognizing the direction where it is pointing to. Improvement for direction inter-

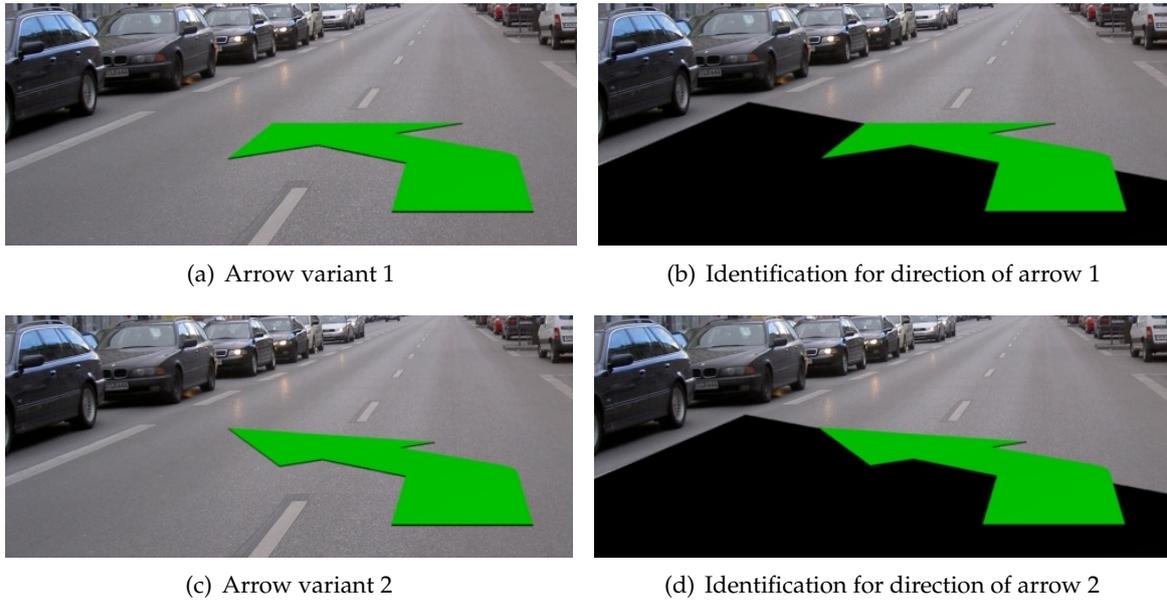


Figure 4.6: Arrow shapes



Figure 4.7: The three Variants of the Arrow-based Waypoint Guidance Scheme

pretation by attaching three or four fins at the shaft has been validated by Tönnes, see [43]. This approach does increase perceptibility of the direction, but are by reason of its height not suitable for route guidance information aligned on the street.

4.2.2 Road Signs

Another idea for route guidance information could be the indication of virtual road signs fixed at the maneuvering point. Sato [39] implemented such an approach, by superimposing navigation flags and direction signs onto the driver's windshield. However, some crucial arguments oppose against such a visualization. For one thing, indication not aligned on the street does enhance the problem of occlusion. For example, pedestrian waiting at a traffic light could be occluded by the traffic sign. Further on such route guidance information contradicts the actual intention of reducing the driver's mental workload, because at a complex crossing some cognitive effort is demanded to interpret the given direction indication. Therefore, in this thesis no of route signs had been implemented.

4.3 Car Fixed Schemes

A further approach for applying conformal route guidance indication is an visualization of information aligned on the street, but seemingly fixed in front of the car. The indication gives evidence about the navigation path by heading towards the defined direction. Such schemes need additional information about the distance to the next turning point.

4.3.1 3D Pointing Devices

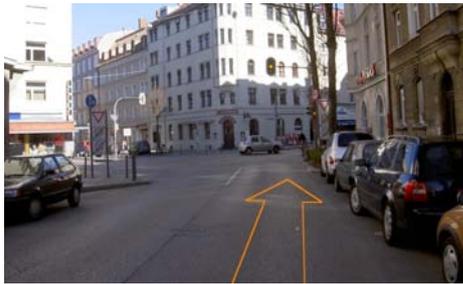
A compass is a common navigational instrument for finding directions on the Earth. It consists of a magnetized pointer free to align itself accurately with Earth's magnetic field, which is of great assistance in navigation. This device adapted as a metaphorical visualization could be an interesting concept for a navigational aid. Direction indication is given by pointing to the defined direction instead of pointing north like a real compass it does. Further investigation about this approach showed, that a compass-like visualization is only useful for guiding to the next maneuvering point, but could not be used as turning information itself. This is due to the fact, that indication of a maneuver has to be perceived early, because the driver has to anticipate and adjust his speed, but a compass concept would not indicate the direction until the maneuvering point is reached. Thus, compass-like indication could be a nice visualization concept for guiding to the next turning point, if the driver only has to follow the street without making a maneuver. An information about the distance to next maneuvering point has to be given with this approach additionally.

4.3.2 Leading Arrow

Another concept using the arrow symbolic could be the car attached variant. A variant of the compass-like concept in combination with an pointing arrow on the leading end could be used as another solution for visualization. Figure 4.8(a) and figure 4.8(b) present a simulated driving sequence for the leading arrow visualization. The arrow is pointing always a specific length ahead of the car. Reducing the occlusion problem a wireframed arrow model should be used to follow the course of the street, see figure 4.8.

4.4 Hybrid Schemes

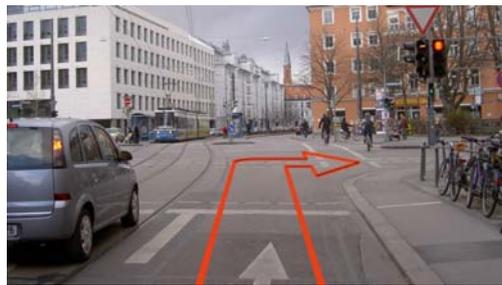
Location fixed indication on it's own bears the risk of late or in worst case of none detection. Reducing the risk of late detection and furthermore to enable the driver to anticipate for the next turning maneuver when route information is out of sight postulates an overall solution. Either a combination with symbolic indication or a hybrid scheme of location and car fixed should be strived for. This section gives a survey about some ideas in terms of hybrid approaches.



(a) 50 meters before the crossing



(b) 15 meters before the crossing



(c) A further simulation

Figure 4.8: Leading Arrows

4.4.1 Combination: Car and Location Fixed

Car and Location fixed refers to a indication concept where the navigation information is aligned along the entire path. The car and the turning point are seemingly connected by the displayed route guidance visualization. This can be provided by single points on path or by highlighting the path with a virtual band. Various combinations of hybrid solutions are possible.

Points on the path Little arrows, points, bars can used as waypoints on the path until the location fixed information is reached, see figure 4.9. These approach reminds on the fairy tale Hansel und Gretel, where the two leave a trail of breadcrumbs for finding their way home.

Increasing information for a certain distance or time is often used as an implicit information in the automotive domain to convey the meaning of proximity and urgency. Supporting parking systems, for example, give information about the distance to other objects in front or behind the car by the frequency of an acoustic signal. Further on, increasing amount of colored bars are used for symbolic distance visualization in common navigation systems, see figure 4.10(a).

Reducing the distance between the waypoints and/or increasing the point's size the closer the turning point comes, can be used as a metaphor for distance indication, see figure 4.10(b).

Pathway Indication Pathway indication refers to a visualization where the complete path from the actual position until the desired destination is highlighted. Highlighting the full



Figure 4.9: Points on the path indication

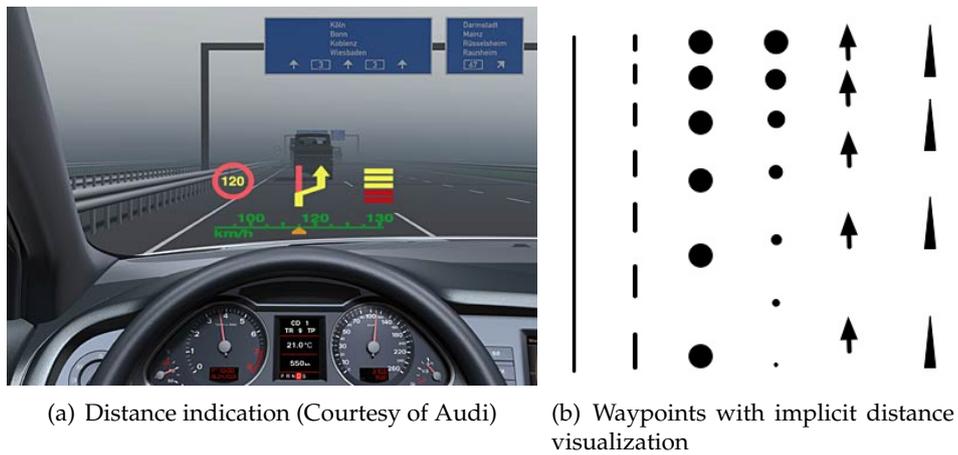


Figure 4.10: Distance Visualizations

path could be hazardous, because a wide area of the street scenery could be occluded. Therefore such an approach should either be avoided or at least carefully designed and evaluated. Reducing the risk by minimizing the indication to its fully extend leads to the idea of giving direction hints by displaying a thin line onto the street. Either one line in the middle of the street or two lines on the border on the street. Enhancing the perceptibility to which direction the line is heading to, could be achieved by given the line a height and coloring the left side different to the right side. Coloring the left side red and the right side yellow is a common visualization used in the seafaring domain. This metaphor has been adapted for highlighting the direction indication in the Augmented Reality navigation systems implemented by the Siemens AG [32].

Another visualization scheme could be a wireframed and stretched variant of the leading arrow, mentioned above. The leading arrow could be stretched in its length so that the one end is still attached at the car whereas the pointing end is fixed at the maneuvering point, see figure 4.8.

4.4.2 Alternation: Mutual Fixed

Presentation schemes which alternate between different indications can be used to compensate the potential problem of late detection as well. Conventional symbolic visualization could be displayed until the driver is in visible proximity to the location fixed navigation aid. Usability studies have to verify the Level-of-Perception to give evidence at which distance the information can be perceived by the driver. Additionally, as the turning point is in proximity but out of sight, location fixed indication could be confusing to interpret and thus another visualization of route guidance information is needed. Providing presentations schemes where symbolic indication is alternating with location fixed still bear the risk that the conformal arrow could not be seen, especially within a complex traffic scenario. Due to this implementing route guidance information for conformal navigation systems should also provide a solution for finding the location fixed aid. The easiest way for finding could be attaching a straight virtual line between the car and the conformal information.

Summarizing, hybrid navigation systems can compensate the mentioned perception limitations by providing symbolic route guidance information and moving to Augmented Reality navigation, when the AR scheme is near enough to be fully perceivable and interpretable.

Up to now, all mentioned presentation concepts have to be seen as a collection of ideas. A lot of research will have to be done to proof their effectiveness, intuitiveness and perception in terms of being non distractive and an improvement in comparison to conventional navigation systems. Some of these concepts has been implemented by means of the open-source program Blender, which is a tool for generating three-dimensional VRML objects.

5 System Setup

Technical Setup of a Prototypical, Automotive Head-Up Display and Implementation of a System for Usability Studies

This chapter introduces the test environment for the design, testing and evaluation of conformal navigation indication schemes. Mainly this environment was designed with the long-term objective to determine the effectivity of conformal navigation indication. Thereby limitations on both sides, the technological and the humans side have to be verified, see figure 5.1.

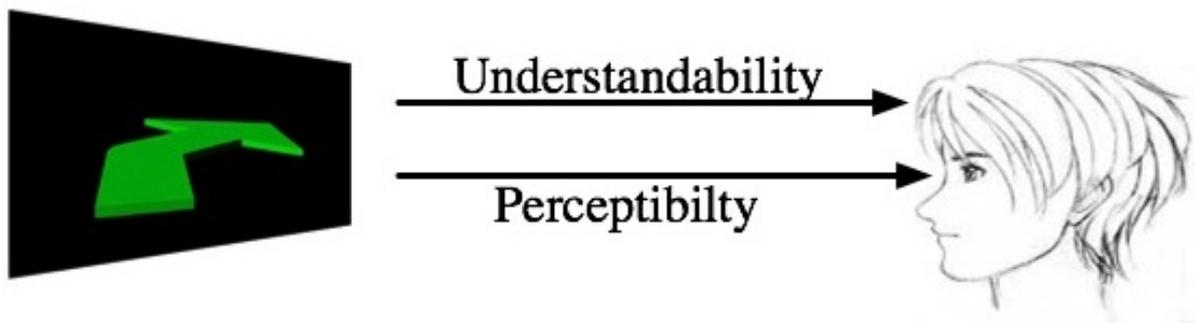


Figure 5.1: Evaluation issues for conformal navigation schemes

This first section gives an explanation of the prototypical automotive head-up display simulator used within this work for identifying indication limitations. This comprises the general setup, the required special optical setup in particular and the limitations which are induced by this optical setup. The next section gives a survey about the application, implemented within the scope of this thesis for testing and evaluation of the indication concepts, in terms of their perceptibility and usability.

It must be pointed out that the hardware of this setup was taken from another project, whereas the software design and development was part of this thesis.

5.1 Hardware Setup

For testing and evaluation a prototypical automotive setup has been constructed at the chair of Augmented Reality at the TU München. A car seat mounted on a rollable construction

serves as the basis for the hardware components. Either a car windshield or plane glass is used as a combiner of the head-up display and can be fixed in front of the seat. The construction is called "Sitzkiste", which is a common German designation for setups of low fidelity driving simulators.



Figure 5.2: Prototypical, automotive HUD called "Sitzkiste"

Before rendering location fixed virtual objects on an HUD, the 3D viewing parameters of the driver's view and the projection unit must be aligned. In other words it is important to capture and maintain information about the position and movement of the driver's head in order to align the view of rendered virtual objects. So head-tracking and calibration are important issues to sustain the illusion of conformal indication. This aspect of the project is part of another diploma thesis, so for further details see [51]

5.1.1 Optical Setup

The key motivation for conformal indication is that the human eye does not have to adjust to another focal depth when viewing from the street scenery onto the navigation information. Location fixed indication is usually placed in different distances to the driver, so a wide range of different focus depth must be covered by the display. But up to now no solution for an display with an adjustable focus depth exist. Thus, the virtual image plane, where the information appears to be displayed, must be placed in a distance where binocular and oculomotor cues does not take an effect on the depth perception. Further details about these depth cues were given in an earlier section, see 2.2.3. Then the human eye does not need to accommodate between the displayed information and the street scenery and providing a sense of depth perception can be solved by the design of navigational arrows, mentioned in the previous section 4. Achieving the desired solution for placing the virtual image plane in the required distance demands a special optical setup.

Optical Theory The main component is the lens, which is a transparent optical device which transmits and refracts light, concentrating and focusing the image beam in a point called the *focal point* F . The image formation through a lens can be described by the lens

formula used in geometrical optics [35]:

$$\frac{1}{d} + \frac{1}{v} = \frac{1}{f}$$

Where d is the *Object Distance*, the distance between the projection display and the lens axis plane, v is the *Image Distance*, and f is the *Focal Length* of the lens, all measured along the optical axis AA'' , see figure 5.3.

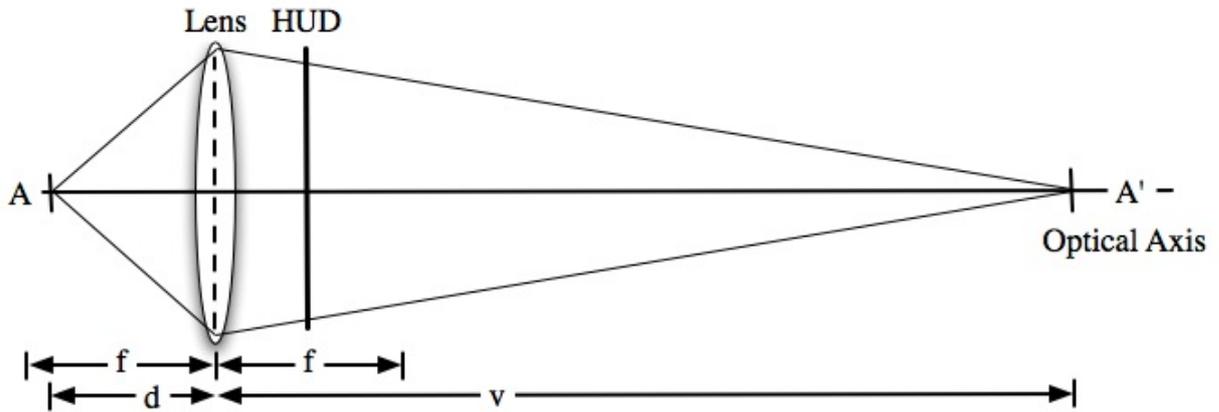


Figure 5.3: Lens law

Other terms which often arises erroneously within the context of conformal indication are *Depth of Field* and *Hyperfocal Distance*. Further details about these terms are explained in appendix B.

Optical Realization To gain this distance the optical setup is built like outlined in the figure 5.4. A conventional desktop screen with a resolution of 1680x1050 is used as the projecting unit and is placed in a distance of 68 cm to the lens. The outgoing optical path of the projection plane is bended in a flat mirror so that it has to pass the optical device the lens with a focal length of 762 mm. By transmitting the lens, the ray of light is refracted in a way that the mirrored plane is then displayed in the driver's windshield. By the use of the lens, a field of view of 34 degrees is generated and the image plane appears to be in an distance of about 11 meters to the driver (see lens formula above). So this manipulation of the image plane is the crucial point to achieve the desired focal length to have the possibility to cover a wide field of depth. This optical setup utilisation offers the solution to provide navigation aids seemingly integrated into the environment. By reason of placing the image in such a distance important display characteristics must be considered.

5.1.2 Challenges and Limitations

As this setup gains the possibility of displaying location fixed information, new challenges and limitations arise. The refraction of the lens leads to the effect, that the original image

the initial task of design developing. Preselected visualization schemes, deemed for worthy, are tested and analyzed whether they match the intended requirements in a pilot study. Accepted or revised design concepts are chosen for the second phase of evaluation within a simulated environment and traverse the same cycle of evaluation as in the phase before. The last and most important phase of verifying the concepts has to be done within real-world studies. Although real-world studies (the last design-evaluation cycle) have not been performed within the scope of this thesis, the possibility for all three phases shall be given by the implemented application.

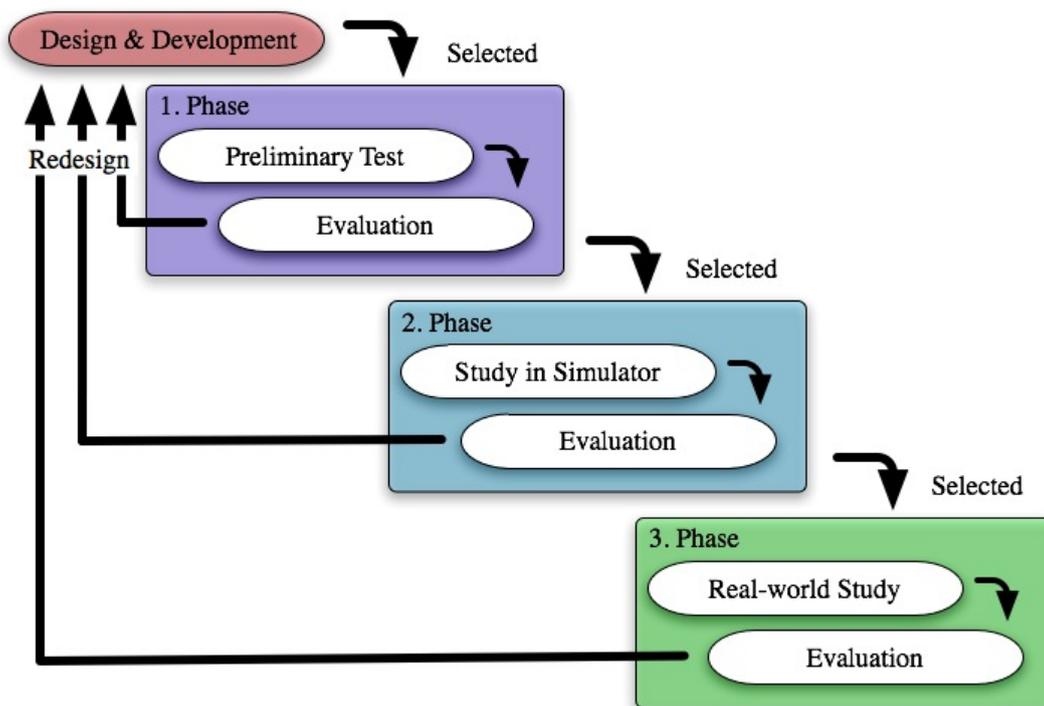


Figure 5.5: Three stages of design evaluation

Features Testing and evaluation of design concepts requires the possibility to built up some guided routes by placing the virtual navigational aids to specific positions. This means, route guidance information is placed in the virtual space in the way that it can be aligned onto the real world, see figure 5.6. Further on, scenarios which comprise the placement of the virtual route guidance information must be storable and loadable for the use as test scenarios during the study.

In the sequel, a brief survey about the general features of the implemented application is given. This is followed by a more detailed explanation about the specific requirements which have been adapted and implemented for each phase of evaluation in the specific subsection.

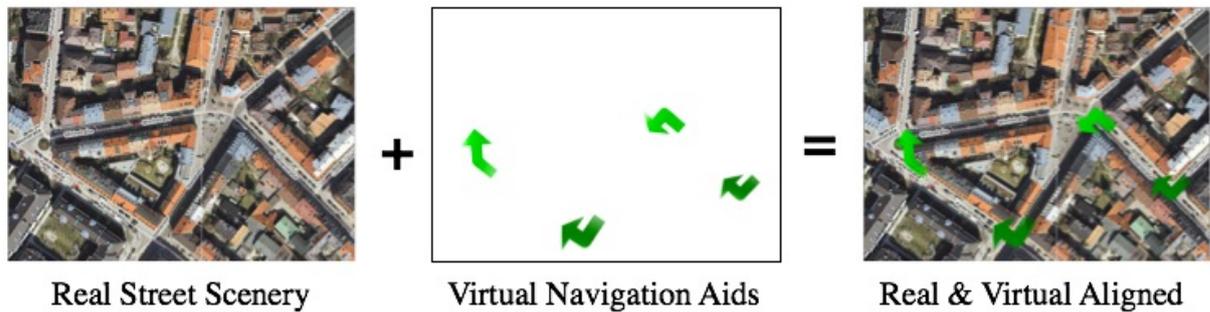


Figure 5.6: Aligning virtual and real environment (adapted from Google-Maps)

General Features The Application is presented by two graphical user interfaces (GUI), one for controlling the system (see figure 5.7) and besides by a viewer window for the rendering of the scene.

- **Loading virtual objects:** Virtual objects can be loaded into the scenario. The file format is VRML, which is a standard for representing three-dimensional vector graphics. After the loading, the objects appear in the GUI for further manipulation and are attached to the virtual scene, which means they are visible in the viewer window.

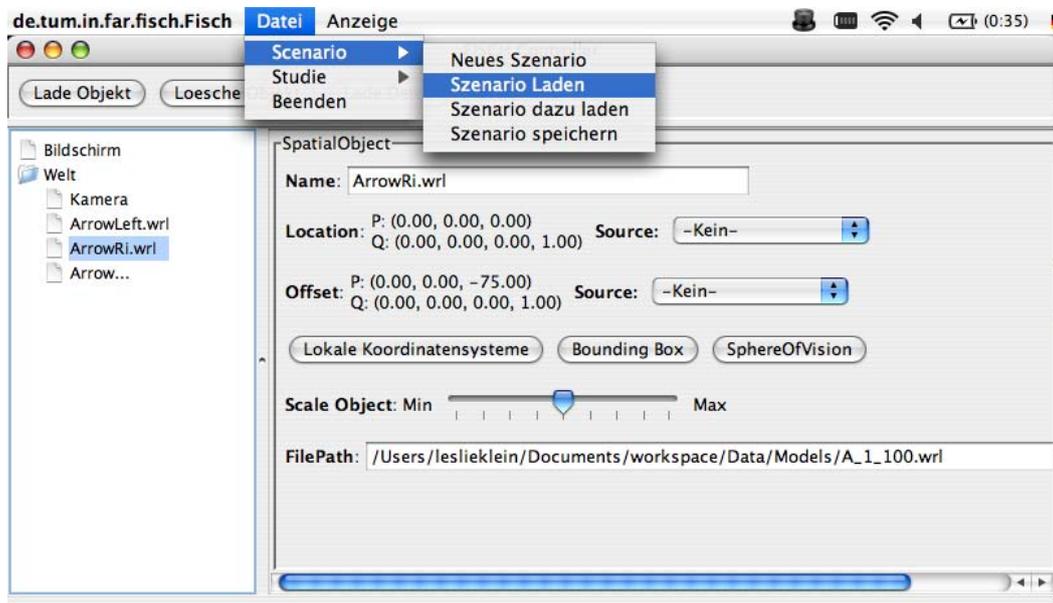


Figure 5.7: GUI of implemented system

- **Placing virtual objects and camera:** Selected from the file-tree in the GUI the object or the camera view can be placed, by attaching the object to one of the following sources.
 - Mouse: Attaching the object to the mouse enables object rotating around the origin by pressing the left mousebutton, translation on the z-axis by pressing the

middle mousebutton and further on translation on the x- and y-axis by pressing the right mousebutton.

- Manual: Attaching the object to the manual tracker enables rotation and translation along all three axis, see figure 5.8. Support for facilitated positioning objects via the manual tracker is given by enabling the indication of the object's coordinate-axis.
- Tracking system: Attaching DTrack, an external infrared optical tracking system installed in the laboratory at the TU Muenchen enables the positioning of the object in dependency of the position and orientation of a tracked object, see figure 5.9. Further development of the application shall enable the binding to a Global Positioning System (GPS) in combination with a gyrocompass for perceiving global position and orientation data to purvey the possibility for real-world studies. A further explanation about tracking was given in the fundamentals chapter 2.1.
- Pose simulation: Attaching the Pose simulation to the camera enables the possibility of simulating straight drives with different speeds. This pose simulation is key triggered and was specially designed for the execution of experiments in the simulator, where people drive directly to a navigational aid.

The trackers are used as follows. Mouse and Manual Tracker are implemented as "relative" trackers, with the intention of manipulating the transformation between two object coordinate systems. They can be used to control camera and objects. The Tracking System and Pose Simulation are treated as "absolut" trackers, which deliver furthermore a frequently updated data stream. For logical reasons they are just attached to the camera, to control the drivers Augmented Reality perspective during simulation or runtime. Additionally to enable the correct rendering of the arrows position in dependency to the driver's head, the integration of a solution for tracking the head is required. This part was scope of another thesis, see [51]. Then the 3D viewing parameters can be determined by the combination of the car's global position (GPS and gyrocompass) with the translation offset of the car's position to the head' position (head tracking). Due to enabling the integration of two tracking systems, the ability to attach the view to both sources had been implemented and the combined transformation is determined by the application.

- **Camera settings:** Beside placing the camera and therewith the rendered view within the scene, the following mentioned settings were enabled. These contain the parameters needed in rendering a three dimensional scene from one viewpoint, in our case they specify the settings for the rendering onto the HUD.
 - Back clip distance: The back clip distance specifies the distance away from the clip origin in the direction of gaze where objects begin disappearing. Objects farther away from the clip origin (eye or screen) plus the back clip distance are not drawn.
 - Front clip distance: The front clip distance specifies the distance away from the clip origin, in the direction of gaze where objects stop disappearing. Objects closer than the clip origin (eye or screen) plus the front clip distance are not drawn.
 - Field of view: The field of view specifies the view model's horizontal field of view in degrees. The FOV refers to the maximum numbers of degrees of visual angle which can be seen instantaneously on the screen and therewith on the HUD.

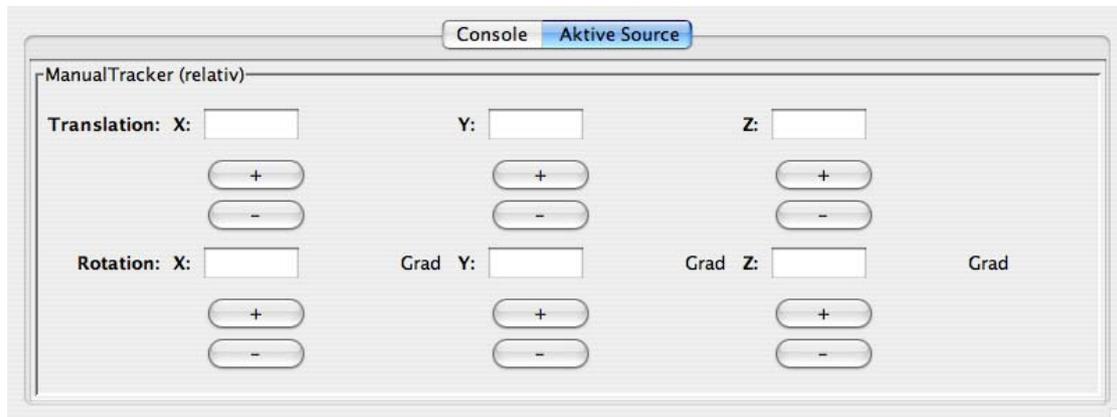


Figure 5.8: GUI of manual tracker

- **Viewer-screen settings:** Changing the position and size of the viewer window is needed when the projecting screen for the HUD is attached as a second screen to the application.

- Screen position: Specifies the position of the viewer window on the (extended) screen.
- Screen size: Specifies the viewer window size.

beziehungsweise

- **Saving the scenario:** The scenario, which comprises all objects within the actual scene with its position, orientation, size, filepath and the settings, camera and viewer-screen, can be saved as a XML-file.
- **Loading the scenario:** Loading a chosen XML-file enables the setting of a complete scenario or selected parts of a scenario.
 - Loading: The actual scenario can be replaced by choosing another one, saved as a XML-file.
 - Combination: The actual scenario can be combined with another one. This means that the whole scenario could be added to the actual one, which includes that the camera and screen settings were replaced and the objects were added. Moreover, only selected parts of the new scenario can be set respectively some of the objects can be added.

First Phase The first phase of the design verification refers to the task of the design developer and is denoted as a pilot study. Having the possibility for displaying the implemented visualization schemes helps to get an insight and helps to identify some limitations in advance. For that reason, the implemented application in combination with the DTrack tracking system shall serve as a test environment for the evaluation of the potential of preselected visualization schemes (see figure 5.9). Using this setup for preevaluation of the design concepts it is necessary to render the route information within an virtual street scenery. Therefore another laborious part of this work was the implementation of a three-dimensional virtual world with different street combinations, see figures 5.10. More pictures of this world

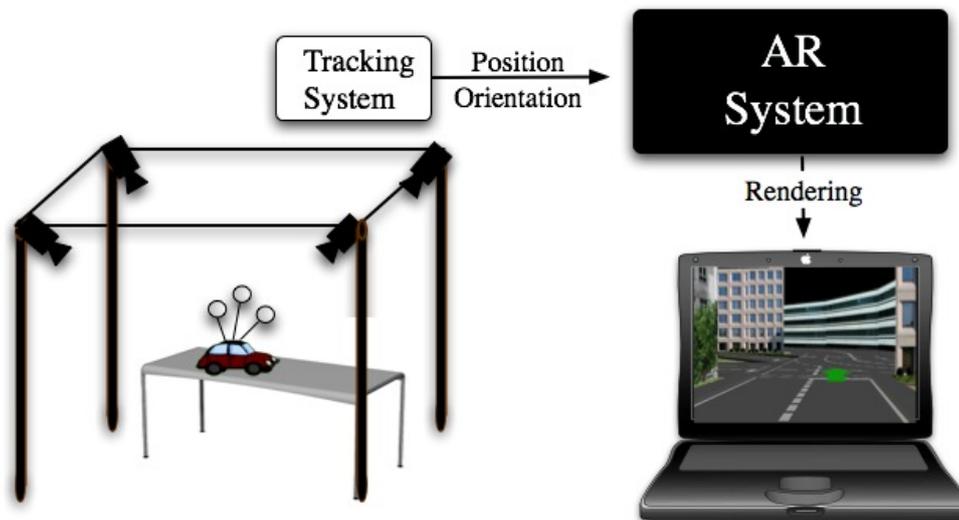


Figure 5.9: AR-System for pre-evaluation

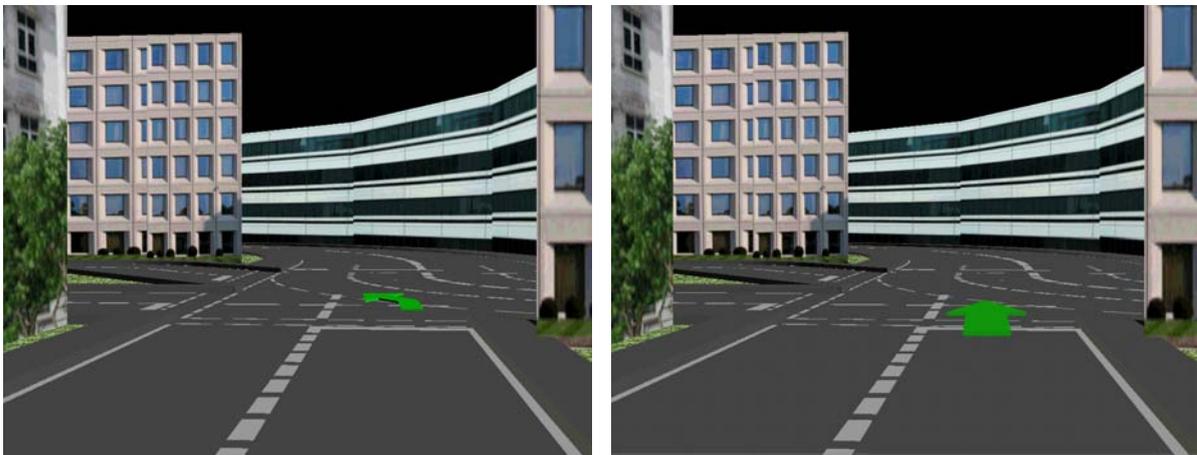
can be seen in the appendix C.1. Navigational arrows can be placed within this world, like it would be for real-world studies, the whole setup with the virtual world can thus be seen as a world in miniature. The DTrack system sends positional data to the application and enables thereby the simulation of driving through the environment by rendering the virtual world in dependency of the position and orientation of the tracked car, like viewing out of the car. Testing virtual arrows in a virtual world does not serve to give reasonable results in terms of their effectiveness and usability, but can give an insight to potential limitations for the development and redesign.

Second Phase The second phase refers to the evaluation of selected visualization schemes with the aid of the prototypical automotive head-up display simulator. Because this setup is fixed-based, the application had to be adapted to enable a pose simulation, see 5.11. This means, pretending a driving scene, where the driver comes closer to the navigational aid. As a consequence thereof the initial implementation had to be adapted in the way that a defined route sequence was given. Then the navigation arrow were rendered superimposed on the HUD dependently of the route and the speed defined before. Basically this means, the user sits in the fixed-based "sitzkiste" and the navigational arrow moves towards the viewer. For the design and execution of user studies an editor was build to allow the development of sequences of driving scenes. Such driving scenes can be loaded into a "study GUI": a GUI which runs driving scenes, triggered by a key event, initiated by the test subjects. Furthermore the "study GUI" logs the performance of the test persons and is used on the side as a poll tool for general questions.

Third Phase The third phase refers to evaluation in real-world studies, see figure 5.12. Up to the integration of GPS and a gyrocompass, the application was implemented to enable



(a) Virtual world without navigation arrows



(b) Virtual world with navigation arrows

Figure 5.10: Different views within the virtual world

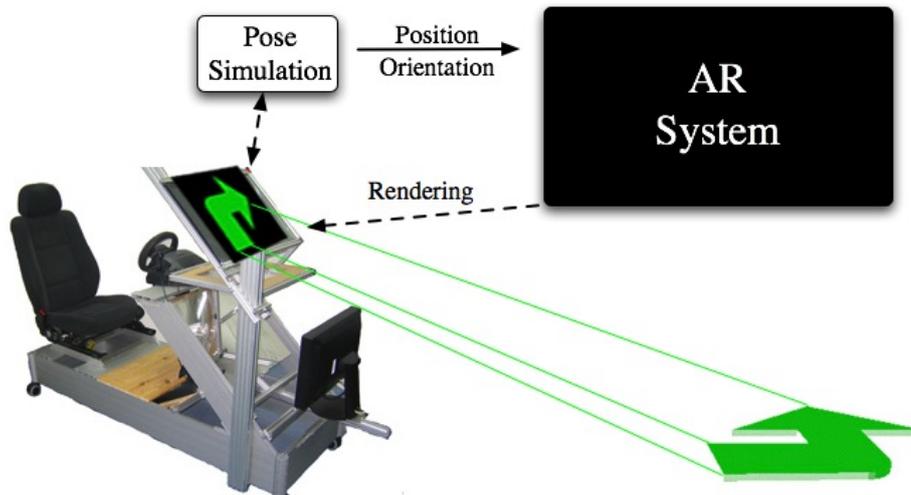


Figure 5.11: AR-System for simulator study

the performance of studies with a car in real environment. For this purpose, a scenario can be created by placing virtual navigational aids to specific position in the environment. This can be done by driving along the specific route. While doing this arrows can be loaded to the current position of the camera. Thereupon they can be placed in detail by the manual tracker. An interesting implementation detail here is, the abstraction of the tracker: The camera position can be manipulated by every tracker, which makes it possible to design a scenario in two ways: Either by driving a virtual car through a virtual environment (which is a copy of the real world area) or by driving a real car through the real world and using the Global-tracking to position the arrow.

For performing real-world studies, the scenario (created in the just described way) can be loaded and the camera view is attached to the Global-tracking solution and the head-tracking solution. The determination of the combined viewing parameters is done by the application. Then the current view is rendered in dependency to the car's global position the driver's head position within the car.

Figure 5.13 gives an brief insight into the application implemented within the scope of this thesis.

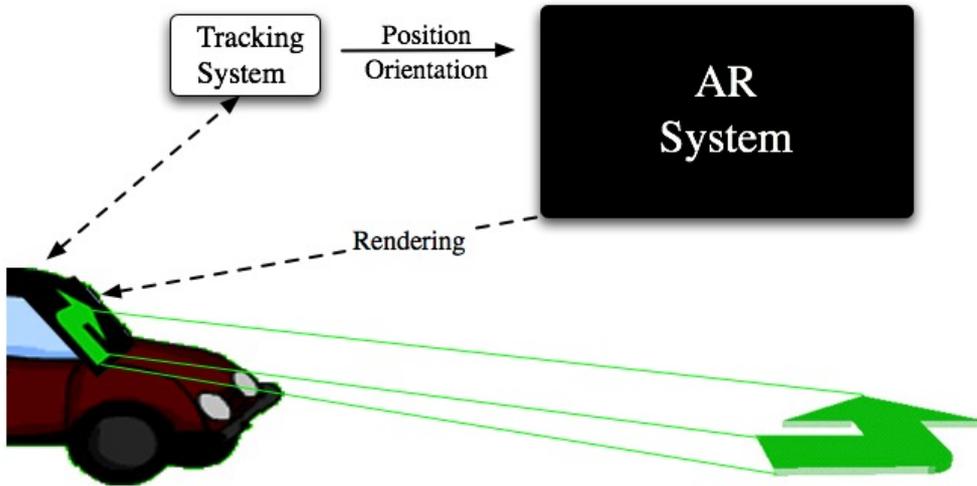


Figure 5.12: AR-System for real-world studies

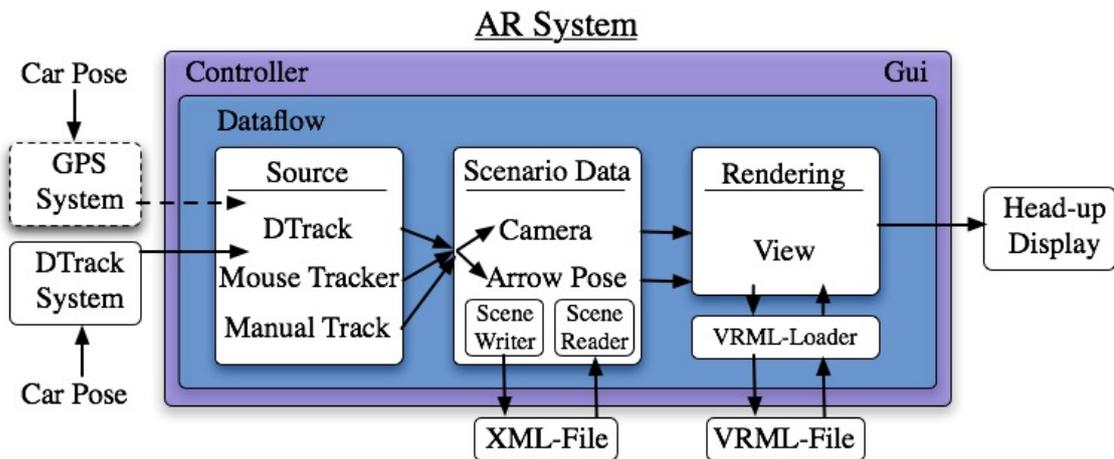


Figure 5.13: AR-System

6 Usability Study for Identifying Distance Limitations for Conformal Indications

Usability Study Procedure, Results and Problems

This chapter reports about the usability test, which was conducted to identify distance limitations in terms of the perceptibility of provided information indication, induced by optical setup of the Head-Up Technology.

6.1 Presentation Concepts

By reason of the indication limitations induced by the optical setup, mentioned in the previous chapter, the choice which kind of navigation indication should be tested within this usability study were reduced to three different forms (see 6.1) of navigational arrows. The general shape were discussed in the previous chapter 4.2.1. With the purpose of identifying which presentation scheme is best perceptible in distance, the attention of this study was focused solely on the arrows shape. The use of colors for enhancing the perception were not taken into account. The decision for coloring the arrow green is based on the consideration that this color provides good perception in front of the gray background of the street surface.

The following three visualization schemes for Augmented Reality navigation aids will be evaluated in terms of their perception in large distances.



Figure 6.1: Type A, Type B, Type C

Five directions (90 degree left, 45 degree diagonal left, straight, 45 degree diagonal right and 90 degree right) had been implemented. Depending on which kind of direction was provided, arrows had different sizes. The straight arrow's dimension got a length of 6.5 m and a width of 2.0 m, the diagonal one a length of 4.8 m and a width of 3.3 m and the 90 degree arrow was 3.5 m long and 2.5 m wide.

6.2 Hypotheses

The following hypotheses shall enable a prediction about the differences in perceptibility of the three alternatives of navigational arrows.

Hypothesis 1: There is a perceptibility difference between the types of direction indication.

Hypothesis 2: There is a perceptibility difference between the types of direction indication when driving 50 km/h.

Hypothesis 3: There is a perceptibility difference between the types of direction indication when driving 100 km/h.

Hypothesis 4: There is a difference between driving 50 km/h and driving 100 km/h in terms of the perceptibility of the type A direction indication.

Hypothesis 5: There is a difference between driving 50 km/h and driving 100 km/h in terms of the perceptibility of the type B direction indication.

Hypothesis 6: There is a difference between driving 50 km/h and driving 100 km/h in terms of the perceptibility of the type B direction indication.

Hypothesis 7: There is a subjective difference between the types of direction indication.

6.3 Experiment

A test environment for the automotive Head-Up Display prototype has been set up to measure how perception in large distances is affected by the presentation schemes.

6.3.1 Participants

In our experiment sixteen individuals, 14 males and 2 females between the ages of 21 and 31 (mean 25.5, standard deviation 2.94), participated. 12 of the participants had never taken part in a study of similar context before and 4 participants had taken part in a simulator test. All participants had normal or corrected to normal vision.

6.3.2 Experimental Setup

The so-called "Sitzkiste", explained in section 5.1, served as the basic component for a fixed-based driving simulator within the experiment. This construction consists of two main components, a mounted car seat and the optical setup which serves as the required Head-Up Technology. The navigation indication was projected at a resolution of 1680x1050 pixels onto a transparent screen located in front of the driver. By reason of the optical setup, the image appeared to be in distance of about 13 meters ahead and with an field of view of 34 degrees. Du the setup one pixel has a relative size in 100 meter distance of about 3.5 cm. A more detailed description about this HUD Technology has been given in section 5.1.1. The system used to display the visualization schemes within the experiment and to record the measurements of the experimental procedure was developed as part of this thesis (see section 5.2). A keyboard, see figure 6.2 for measuring the participant's input was attached to the system.

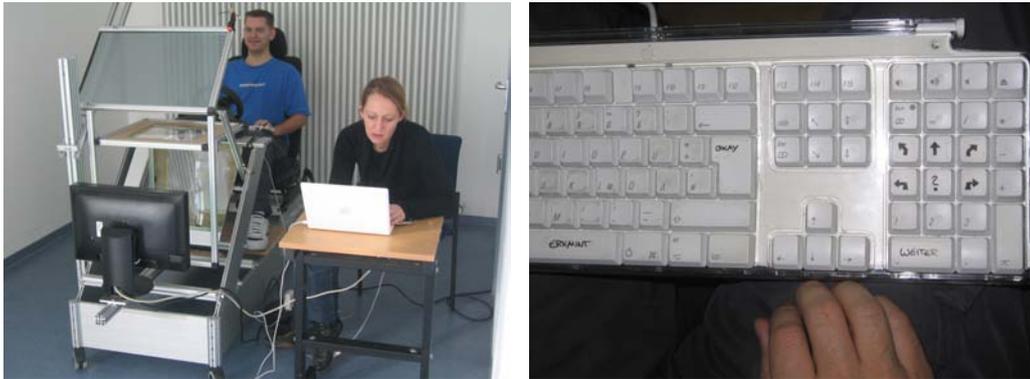


Figure 6.2: Experimental Setup

In order to test the visualization schemes in large distance without being impaired by visual obstacles, the experiment was set up in an circa 120 meters long corridor in the TU München.

6.3.3 Test Procedure

Before the experiment the participants had to fill out a demographic questionnaire (see appendix A.1) and were instructed about the objectives of this study. After taking a seat, the participant got introduced and familiarized with the process and task of the study by executing a test round. A within-subject [5] design was used to test perceptibility of the the three shapes of navigational arrows, so each participant had to do all three tests in a row, but in a permuted order. Hence the experiment comprised three trials. Until the time of the experimental process head-tracking had not been integrated, so each trial started with positioning of the users head relating to the HUD to ensure that the participant was looking trough the HUD on-axis (see figure 6.3). Otherwise the navigational arrow would not be aligned correctly in the environment and/or the view would have been distorted by the refraction of the lens.

The next step of each trial, the actual test procedure was started by the participant himself through pushing a marked button on the keyboard. An arrow appeared in a distance between 250 and 320 meters on the HUD and moved seemingly towards the test person to provide the impression like the car would be driving in the real world towards the conformal navigational aids, see figure 6.4. When the participant thought he has identified the correct direction indication (Turning left 90 degrees, Turning left 45 degrees, Straight, Turning right 45 degrees, Turning right 90 degrees) he had to push another button. The arrow disappeared and the indication of the next arrow was started not until the participant had set the identified direction via different buttons and pushed the "Next-Button". Within one round the direction of 30 (six times each direction) arrows had to be identified. Furthermore half of the arrows moved with a speed of 50 km/h and the other half with a speed of 100 km/h towards the participant. After each trial the test participants had to tell about their overall workload by filling out NASA Task Load Index (NASA TLX), see appendix A.2.

After the whole experiment the participants were asked to fill out a questionnaire (see appendix A.3) to describe their subjective judgement on the three visualization schemes. They

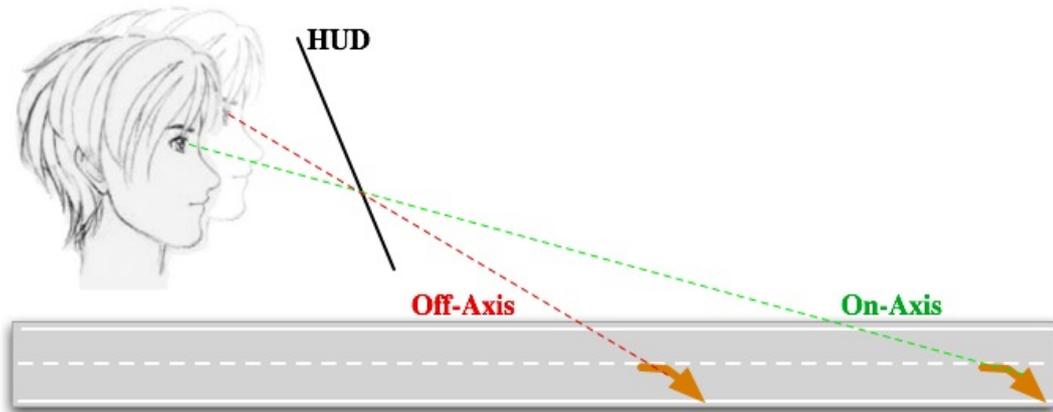


Figure 6.3: On-axis and off-axis

were asked by which of the three visualization schemes they could determine the direction information faster and more precisely and which kind of presentation they liked more. Furthermore, they were asked at which distance they could identify the navigation indication and with which speed they moved towards the arrows. In addition they were asked if they can imagine advantages of such conformal arrows in comparison to conventional navigation systems. Finally they were asked for ideas and suggestions how conformal arrows could look like.

6.3.4 Experimental Design

For examination of hypotheses samples of the population are selected for the test. Samples can thereby be dependent, participants serve in more than one test, or independent. In this study we used within-subject design which means we used dependent samples and each subject had to be tested for all different visualization schemes. A within-subject design has the advantage of reducing the error variance associated with individual differences.

6.3.4.1 Independent Variables

The independent variables are those that are deliberately manipulated to invoke a change in the dependent variables. In our experiment the independent variables were the selected visualization scheme (Variant A, B, C) for navigation information, denoted as the variable *treatment T* and *speed S* (50 and 100 km/h).

6.3.4.2 Dependent Variables

By contrast to the independent variables, dependent variables declare what is measured in the experiment. The dependent variables are those that are observed to change in response to the independent variables. Some dependent variables were used to quantify the quality

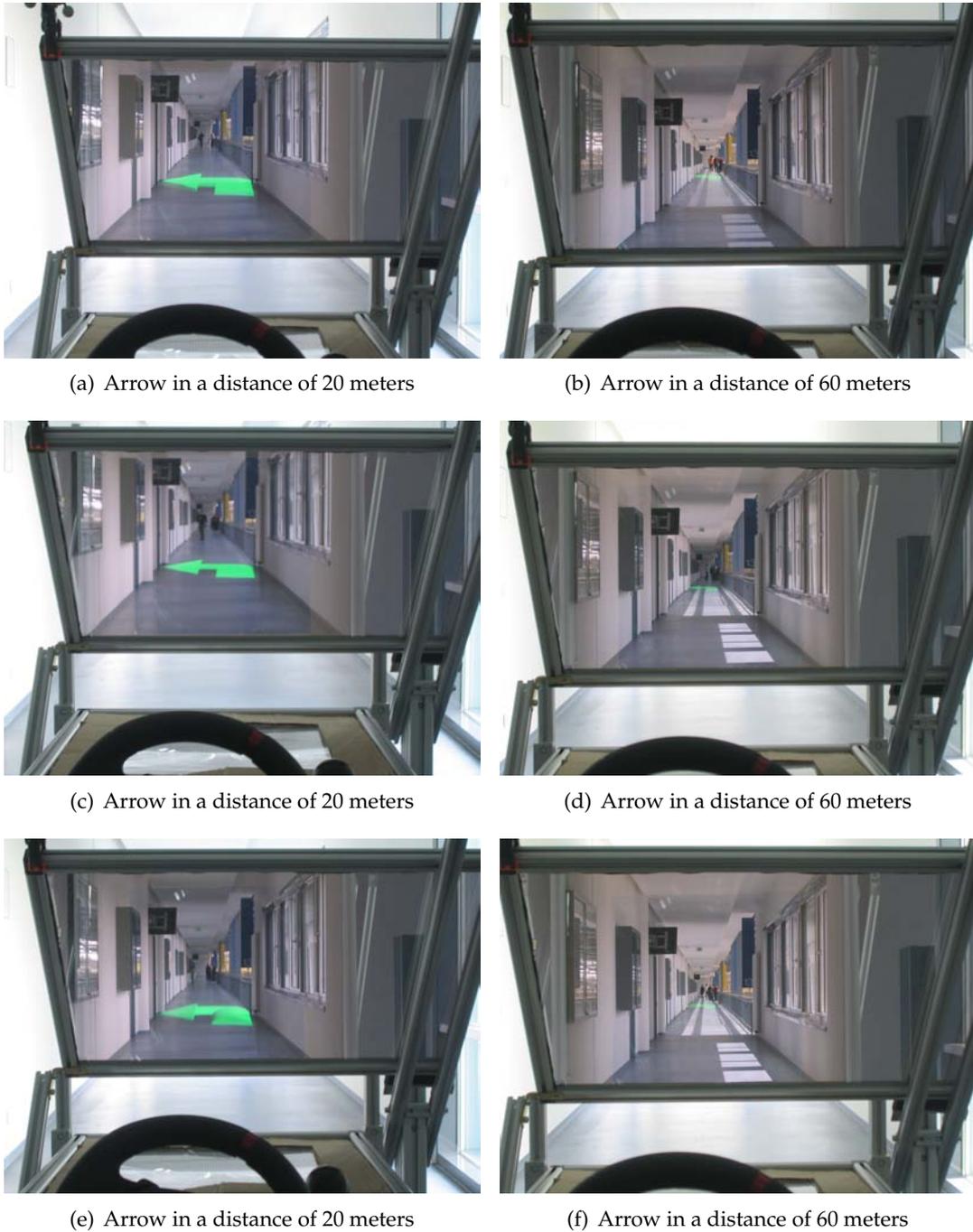


Figure 6.4: Navigation arrows superimposed in the Head-Up Display

of the visual schemes. The *distance D* was the distance from where the participants were able to identify the offered direction indication. The distance variable helps determine the perceptibility of each presentation scheme. The *error quotient E* was the percentage of wrong answers. The error quotient helped to measure at which distance the participants were able to determine the correct direction indication reliably.

6.4 Results and Discussion

The main goal of the study of this thesis was to contrast three different groups of navigation arrows in terms of their perceptibility. Perceptibility was measured on the basis of the distance from where the participants were able to identify the offered direction indication. Correct conclusions relating to the hypotheses requires the examination of specific pre-conditions. Our context signified that two assumptions had to be prevalent. Firstly, the homogeneity of variances, which means the variance of data in groups should have been the same. And secondly the normality, which means the distributions in each of the groups had to be normal. Additionally, selecting the correct evaluation method was decisive for the quality of the results.

To identify distance limitations for information indication it was necessary to find out which measurements can be used for the determination. This means it was important to know which statements about the direction were correct and which were not. The independent error variable *E* was used to determine deficiency in perceiving within the study. As a consequence distance measurements with incorrect statements about the direction were not incorporated in the evaluation. Solely correct statements and the appendant distance were used as a sample. This was feasible without suffering losses, because the participants were instructed, that it does not matter to identify the offered arrow direction as quick as possible, but rather to be sure about the direction indication. In consequence only few mistakes were made and thus disregard of these data was acceptable. Due to this, the independent variables *T* (arrow type) and *S* (speed) could be evaluated by using solely one dependent variable, the distance *D*.

Because of the matter that more than two samples had to be contrasted, the usage of the *t*-test was not permissible [37, 5]. Accordingly, to identify significant differences between three groups with regard to one dependent variable required the use of the one-way ANOVA. A more detailed description about the use of statistical methods for empirical evaluation was given in the previous section 2.3.2.

6.4.1 Objective Measurements

Objective measurements were gathered from 16 participants for three times 30 direction indications. 1440 measurements were recorded, 480 for each visualization scheme. For identifying a threshold for information indication, distance measurements which correlated to the wrong answers have not been taken into account, like explained above. 468 measured values of arrow type A, 476 measured values of arrow type B and 470 measured values of type C were used.

Hypothesis 1: *There is a perceptibility difference between the types of direction indication.* Table 6.1 and table 6.2 presents the measurement results for the dependent variable distance with respect to all three visualization schemes in general. Table 6.1 shows the ANOVA results, the F-Ratio and it's significance indicates that there is a difference between the groups. Additionally it presents the significance of the Levene-test results, the test for homogeneity of variances, which is the required assumptions for using Scheffe as an adequate post-hoc-test. Table 6.2 presents the results, evaluated with the post-hoc Scheffe-test, to give evidence which of the groups differ. The arrow type C, the rounded arrow scheme, which was actually designed to enhance the perception, turned out to decrease perception significantly. The results gave clear evidence that different visualization schemes have an profound effect upon distance limitations in terms of perceptibility.

	Levene	ANOVA
F-Ratio		21,152
Sign.	,001	,000

Table 6.1: Homogeneity test and analysis of variance for Hyp.1

alpha	Arrow type A	Arrow type B	Arrow type C
Arrow type A		,698	,000
Arrow type B			,000
Arrow type C			
Mean [m]	149,3725	145,1416	119,3680
Std.dev.	79,22143	77,83557	72,45211

Table 6.2: General difference between arrow types

Hypothesis 2: *There is a perceptibility difference between the types of direction indication when driving 50 km/h.*

Table 6.3 and table 6.4 presents the results for the analysis of the experimental data when simulated driving with 50 km/h. In table 6.3 the significance of the F-ratio gives evidence about difference between the three visualization schemes and the Levene significance proved the homogeneity for the variances. Table 6.4 shows the Scheffe-test results about which group differs. Measured mean values of the perception distances of all three visualization schemes are in comparison to the hypothesis 1 greater, participants perceived the correct direction indication earlier. Driving at a lower speed does enhance perceptibility. But the results between the types of visualization is similar to the results of the hypothesis 1. The perceptibility of the round shaped navigational arrow is significantly worse than the two others.

Hypothesis 3: *There is a perceptibility difference between the types of direction indication when driving 100 km/h.*

Table and 6.6 shows the measured results with respect to all three visualization schemes, but in this examination when driving at a speed of 100 km/h. Homogeneity of variances is given and a difference between the arrow schemes definitely exists. Increasing speed does

	Levene	ANOVA
F-Ratio		10,525
Sign.	,134	,000

Table 6.3: Homogeneity test and analysis of variance for Hyp.2

alpha	Arrow type A	Arrow type B	Arrow type C
Arrow type A		,637	,000
Arrow type B			,003
Arrow type C			
Mean [m]	159,2215	152,4791	128,1428
Std.dev.	79,82772	76,27329	75,08621

Table 6.4: Difference between arrow types when driving 50 km/h

result in an decreasing distance of perceptibility. The participants perceived the provided direction indication later. The result of the difference between the types of arrows stays the same like in the hypotheses before, the rounded arrow scheme C was significantly worse than than both other schemes.

	Levene	ANOVA
F-Ratio		10,874
Sign.	,003	,000

Table 6.5: Homogeneity test and analysis of variance for Hyp.3

Hypothesis 4: *There is a difference between driving 50 km/h and driving 100 km/h in terms of the perceptibility of the type A direction indication.*

Table 6.7 presents the measurement results for the dependent variable distance with respect to the speed analysis of the arrow scheme A. Driving with a higher speed results in a significantly decreased perceptive distance. On the one hand delay in response does generate a minor distance when driving with higher speed than when driving with lower speed. Exemplary, one second delay when driving 100 km/h means a distance difference of 27.8 meters and when driving 50 km/h 13.9 meters. And furthermore higher speed results in faster changes of the displayed pixels, thus perception of the direction indication becomes more problematic.

Hypothesis 5: *There is a difference between driving 50 km/h and driving 100 km/h in terms of the perceptibility of the type B direction indication.*

Table 6.8 shows the speed analysis of the measurements for the arrow type B. The speed effect results are similar to the ones of arrow type A. There is a difference for different speed, but in comparison to A the outcome is a bit less significant, which means the perceptibility difference in terms of speed is not so high.

Hypothesis 6: *There is a difference between driving 50 km/h and driving 100 km/h in terms of the*

alpha	Arrow type A	Arrow type B	Arrow type C
Arrow type A		,979	,000
Arrow type B			,000
Arrow type C			
Mean [m]	139,3538	137,9264	110,7413
Std.dev.	77,49318	78,83537	68,83861

Table 6.6: Difference between arrow types when driving 100 km/h

alpha	50 km/h	100 km/h
50 km/h		,007
100 km/h		
Mean [m]	159,2215	139,3538
Std.dev.	79,82772	77,49318

Table 6.7: Difference between 50 km/h and 100 for arrow type A

perceptibility of the type C direction indication.

Table presents the analyzed data from the measurement of the impact of different speed on the third arrow scheme C. The difference is significant, like in the hypotheses before and is almost equal to the significance of type A.

Table 6.10 gives an overview about all important data, gathered within the experiment. It summarizes the mean, minimum and maximum values of the measured perceptibility distances. The best distance of perceptibility is highlighted green, whereas the worst is marked with the color red. Figure 6.5 shows graphical the perceptibility differences of the three different types of navigational arrow. Figure 6.6 shows the differences in perceptibility of the different schemes in terms of speed.

The results give clear evidence that perceptibility in distance is influenced by the arrows shape and therewith gives room for improvement. Contrary to the assumption, that the arrow type C does enhance the perceptibility, this visualization scheme was the worst.

6.4.2 Subjective Measurements

Hypothesis 7: *There is a subjective difference between the types of direction indication.*

The NASA Task Load Index (NASA TLX) questionnaire was used to get an overall workload score, how the participants perceived their mental demand for each trial during the experiment, see appendix A.2. Table 6.11 and table 6.12 presents the measured results. The Levene-test shows that the homogeneity of variances is not given, so the Tamhane-test had to be used as the adequate post-hoc analysis. No significant difference was measurable, so the participants felt no specific difference between the arrow schemes in terms of their workload.

The results of the questionnaire (see appendix A.3) to describe the subjective judgement on the three visualization schemes, were similar to the objective results. Participants were

alpha	50 km/h	100 km/h
50 km/h		,041
100 km/h		
Mean [m]	152,4791	137,9264
Std.dev.	76,27329	78,83537

Table 6.8: Difference between 50 km/h and 100 for arrow type B

alpha	50 km/h	100 km/h
50 km/h		,009
100 km/h		
Mean [m]	128,1428	110,7413
Std.dev.	75,08621	68,83861

Table 6.9: Difference between 50 km/h and 100 for arrow type C

asked which of the three presentations schemes for conformal navigation arrows they did regard as best perceptible and which as the worst perceptible one. 10 of the participants stated the best perceptibility was given by the variant B, the flat arrow. 4 participants mentioned the variant A, the cubed shaped one and 2 participants termed the variant C, the rounded one for best perceptible. The answers on the question for preferences fully corresponded with the the answers of perceptibility except for one participant, who stated that he did not notice a perceptible difference between the arrow schemes. Further on, the participants were asked about their subjective feeling with which speed they thought that the arrows were moving towards them and at which distance they were able to perceive the direction indication. Statements to the subjective speed impression showed a clear disparity to the actual speed. The most mentioned speed was 30 km/h and only a few data indicates the subjective felt speed of more than 60 km/h. This effect was due to the fact that the arrows were moving towards the participants and not vice versa, so speed estimations had to be done without the aid of the surrounding scene. The majority of perceptibility distances estimations varied from 15 meter up to 100 meter. The question whether the participants could image an advantage of such route guidance information in comparison to conventional navigation systems resulted in a clear preference of conformal indication. Only one participants denoted that such indication demands a high concentration and another commented the risk of being potential distractive. Observation and statements during the experiment exposed the phenomena that some participants raised their head for the purpose of improving the view onto the displayed information.

6.5 Conclusion

The experiment gave clear evidence that different visualization schemes have an profound effect upon distance limitations in terms of perceptibility. In contrary to the original expectation that the round-shaped arrow is best perceptible in distance the experiment turned out

6 Usability Study for Identifying Distance Limitations for Conformal Indications

Distance	50 km/h			100 km/h			Total km/h		
	A	B	C	A	B	C	A	B	C
Min. [m]	25,85	24,37	13,85	13,72	17,69	11,08	13,72	17,69	11,08
Max. [m]	306,18	297,61	309,44	298,39	302,72	286,17	306,18	302,72	309,44
Mean [m]	159,22	152,48	128,14	139,35	137,93	110,74	149,37	145,14	119,37

Table 6.10: Overview of all distance data

	Levene	ANOVA
F-Ratio		,740
Sign.	,378	,483

Table 6.11: Homogeneity test and analysis of variance for Hyp.7

that this presentation scheme decreased perceptibility. The arrow variant A, the cube-shaped one, was best perceptible in distance. Further research has to prove whether the distance limitations in terms of perceptibility could be improved by coloring the arrow edges or by the use of another visualization.

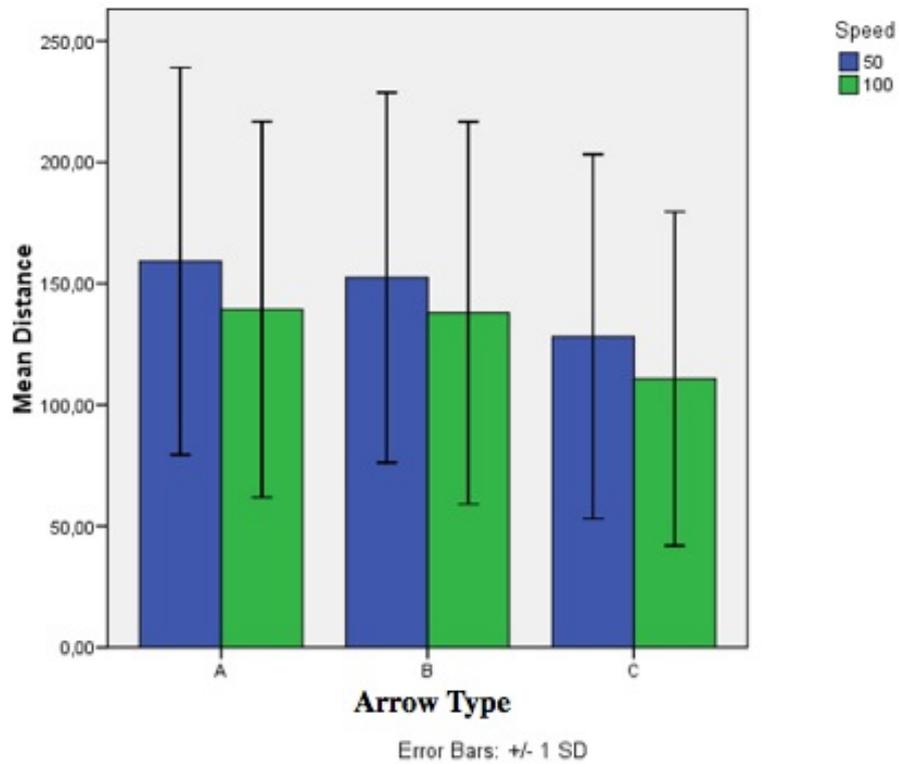


Figure 6.5: Perceptibility of different schemes in terms of type

alpha	Arrow type A	Arrow type B	Arrow type C
Arrow type A		,835	,483
Arrow type B			,828
Arrow type C			
Mean	30,3750	33,1250	35,9375
Std.dev.	12,27939	14,31491	12,07459

Table 6.12: Subjective difference between the arrow types

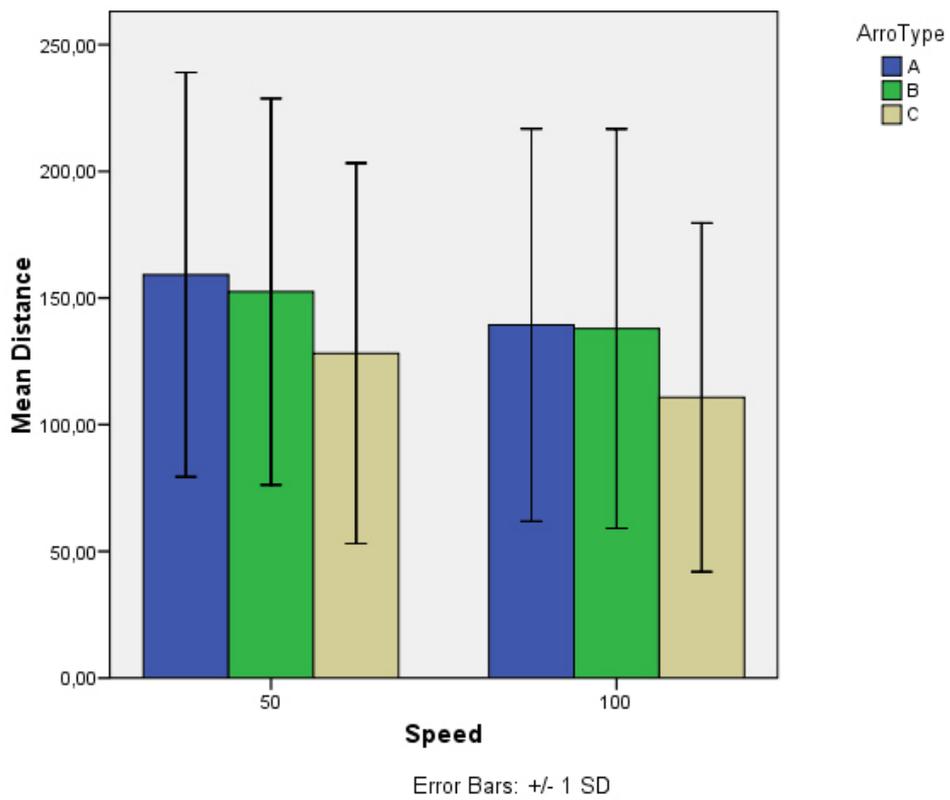


Figure 6.6: Perceptibility of different schemes in terms of speed

7 Conclusion

Results of the Work and Proposals for Future Research

This chapter concludes this thesis with a short review and discussion about the results and experience made during this work. In addition, it gives an overview about possible future work regarding the development of navigation systems with conformal route guidance indication.

7.1 Results and Discussion

In this thesis we investigated Augmented Reality based techniques as a novel approach for user interaction in terms of navigation systems. Important aspects related to the development of conformal route guidance indication have been introduced and in partly evaluated. Special attention was given to the design and development of conformal visualization schemes and to the implementation of an application for evaluation of limitations in terms of the design and technology.

Design The most challenging issue was to counterbalance the adversarial key features of providing depth perception and being perceptible in distance at the same time. The optical setup to enable the driver having an understanding of the position of visual aids within the three-dimensional world is based on placing the image plane in a distance where the effectiveness of binocular or oculomotor cues are minimized so far as distance interpretation is depending solely on monocular cues. Due to this fact approaches to enhance perceptibility of distant information by increasing the size of navigational arrows in distance are inexpedient because this would counteract the monocular cue, which is denoted as the relative size, for depth perception. For similar reason enhancing perceptibility of distant information by displaying navigation arrows more “up-standing” are inexpedient as well. In consequence navigational arrows must be displayed with in their constant size, which means that an arrow with it’s real world size of about 4 x 3 meters appears in large distance is very small size. Furthermore this constraint in combination with the indication limitations induced by the optical setup leads to restricted perceptibility of navigation information in distance. Thus, emphasis was placed on improving perceptibility by the design of navigational arrows. Beside these design contemplation a collection of ideas about presentation concepts for pathway indication to the location fixed information has been given. Finally, most of these concepts have been implemented as three-dimensional objects and can therefore be used for further evaluation.

Implementation The second major part of this thesis was the implementation of an application for testing and evaluation of the designed indication concepts. Mainly this environment was designed with the long-term objective to determine the effectivity of conformal navigation indication. Thereby physical and psychological performance and efforts of humans in relation to new technologies as well as technological limitation itself have been identified. With this application a good basis for preliminary usability studies and for future real-world studies is given.

Experiment Because the identification of indication limitations was considered to be of highest priority an usability study had been performed. The implemented application in combination with the prototypical HUD simulator had been used for performing this experiment. The goal of this study was to identify a distance threshold for conformal indication and to determine whether this threshold can be influenced by the design of the presentation schemes. The experiment gave clear evidence that different visualization schemes have an profound effect upon distance limitations in terms of perceptibility. The mean value of all distance measurements for the best perceptible arrow, the cubed-shaped one, was 149,37 meter while the worst, the rounded-shaped one, was 119,37 meter.

7.2 Future Work

This section gives some suggestions for possible future work.

Perception of depth Providing depth perception is essential to enable the driver having an understanding of the navigation aid's position within the three-dimensional world. The approach to reduce depth information on monocular cues has to be evaluated. Studies have to reveal whether humans are able to estimate the correct distance.

Perceptibility in distance Further investigations have to proof the effect of coloring the arrow edges in different colors for enhancing perception in large distances, see figures in appendix C.2.

Another important aspect is to adapt the visualization to the distance threshold, as displaying conformal information beyond this point is useless. Therefore a visualization can be displayed according to the well-known concept Level-of-Detail as it is used in computer graphics: In short distances conformal navigation aids are used and in greater distances other types of indications are used, which e.g. give a hint for a navigational aid. Additionally, investigations of concepts for the transfer between the indication in great distance and AR route guidance have to be done.

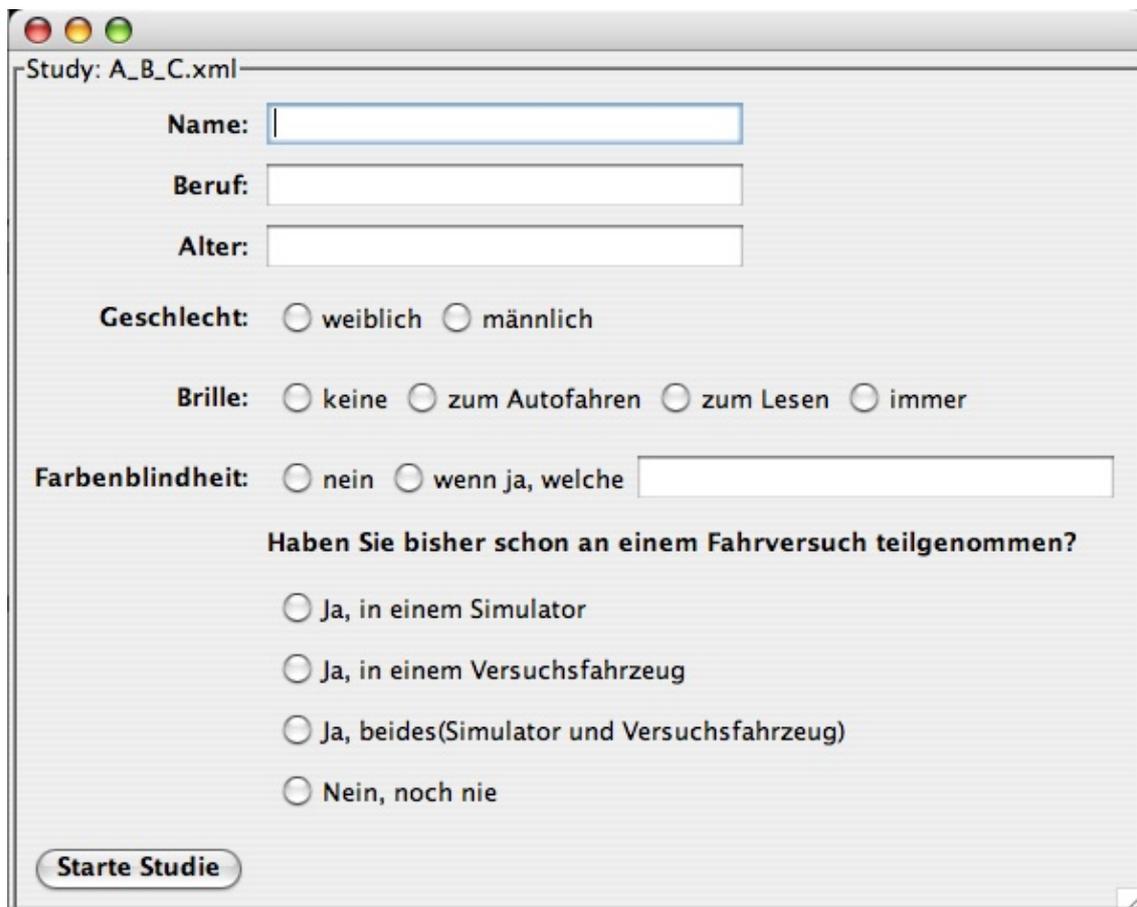
Real-world studies Integration of GPS and gyrocompass and the incorporation of the whole system into a real car enables the study of the effects of conformal indication in the real environment. The impact of this new approach on people with varying perceptual and cognitive capabilities within an environment where there is a complex, continually changing visual scene are crucial for evaluation [11]. Furthermore previous research [42] suggests

7 Conclusion

that cognitive tunneling is induced by more egocentric visual displays and results in poorer information extraction and situation awareness as compared to an exocentric display of the same information. Thus the omnipresent nature of the HUD information has to be verified in terms of potentially being the cause for the effect of perceptual and cognitive capture. Furthermore the effect of occlusion through other cars and objects has to be determined.

A Questionnaire

A.1 Demographic Questionnaire



The image shows a screenshot of a web-based questionnaire interface. The window title is "Study: A_B_C.xml". The form contains the following fields and options:

- Name:** A text input field.
- Beruf:** A text input field.
- Alter:** A text input field.
- Geschlecht:** Radio buttons for "weiblich" and "männlich".
- Brille:** Radio buttons for "keine", "zum Autofahren", "zum Lesen", and "immer".
- Farbenblindheit:** Radio buttons for "nein" and "wenn ja, welche", followed by a text input field.
- Haben Sie bisher schon an einem Fahrversuch teilgenommen?** Radio buttons for "Ja, in einem Simulator", "Ja, in einem Versuchsfahrzeug", "Ja, beides(Simulator und Versuchsfahrzeug)", and "Nein, noch nie".
- Starte Studie:** A button at the bottom left.

Figure A.1: Demographic Questionnaire

A.2 NASA-TLX Questionnaire

Nasa TLX

Mental Demand (geistige Anforderung)
In welchem Masse stellte diese Studie geistige Anforderungen, also denken, beobachten, entscheiden?

low < [] > high

Physical Demand (körperliche Anforderung)
Wieviel körperliche Anstrengung, also stillhalten und gleichzeitig drücken war erforderlich?

low < [] > high

Temporal Demand (zeitliche Anforderung)
Welchen Zeitdruck empfanden Sie aufgrund der Geschwindigkeit in der auf die Pfeile zugefahren wurde?

low < [] > high

Effort (Aufgabenerfüllung)
Wie zufrieden sind Sie mit dem Grad der Aufgabenerfüllung, also der Pfeilerkennung?

good < [] > poor

Performance (Anstrengung)
Wie sehr mussten Sie sich bei der Studie insgesamt anstrengen (geistig und körperlich)?

low < [] > high

Frustration Level (Frustiert)
In welchem Masse fühlten Sie sich bei der Studie gestresst?

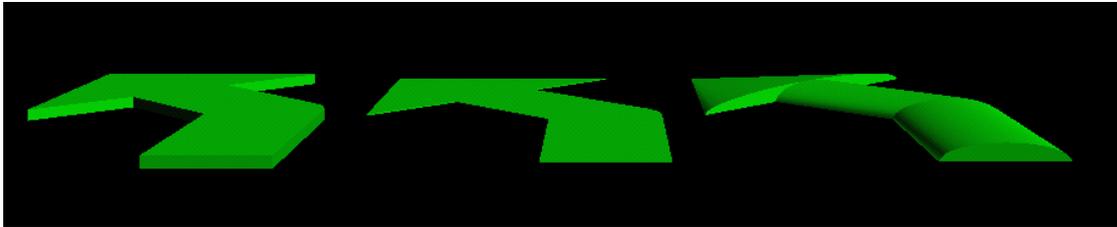
low < [] > high

OK

Figure A.2: NASA Task Load Index-Questionnaire

- Mental Demand (geistige Anforderung):
 - Low High
- Physical Demand (körperliche Anforderung):
 - Low High
- Temporal Demand (zeitliche Anforderung):
 - Low High
- Effort (Aufgabenerfüllung):
 - Good Poor
- Performance (Anstrengung):
 - Low High
- Frustration Level (Frustiertheitsgrad):
 - Low High

A.3 Subjective Questionnaire



1. Welches Anzeigekonzept halten Sie für am besten und welches für am schlechtesten erkennbar und warum?
2. Bitte geben Sie eine Reihenfolge für die Beliebtheit der 3 Pfeildarstellungen an:
 - a) Gefällt mir am besten
 - b) Gefällt mir mittel
 - c) Gefällt mir am schlechtesten
3. Welche Geschwindigkeiten wurden gefahren? (Mehrfachnennungen möglich, bitte einkreisen)

10	20	30	40	50	60	70	80
90	100	110	120	130	140	150	km/h

4. In welcher Entfernung glauben Sie, konnten Sie den Pfeil erkennen? (Bitte den Mittelwert in Metern angeben)
 - a) Pfeil A in Metern:
 - b) Pfeil B in Metern:
 - c) Pfeil C in Metern:
5. Können Sie sich vorstellen, dass solche Navigationpfeile zu herkömmlichen Navigationssystemen Vorteile bieten? Warum?
6. Haben Sie noch weitere Vorschläge/Ideen wie solche HUD-Navigationspfeile aussehen könnten?

B Hyperfocal Distance

In optics the area of a scene that appears sharp in an image is termed as the *Depth of Field* (DOF) [35], see figure B.1. The DOF is determined by the object distance, the focal length of the lens and the relative aperture. The extend of the DOF area in front and behind the focused object varies on the distance on which the lens is focus on.

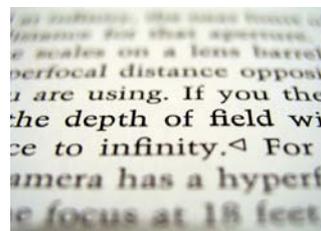


Figure B.1: Example for a small depth of field (courtesy of Wikipedia)

When the lens is focused on infinity, the nearest point that is considered acceptably sharp is the *Hyperfocal Point*. By focusing on the hyperfocal point, everything beyond it to infinity remains in acceptable focus, and objects halfway between the viewer and the hyperfocal point will also be perceived acceptably sharp. Focusing on the hyperfocal point is the focus distance with the maximum depth of field and is called the *Hyperfocal Distance*. Focusing beyond the hyperfocal distance does not increase the DOF behind the focused object, because it already extends to infinity, but decreases the DOF in front of the object.

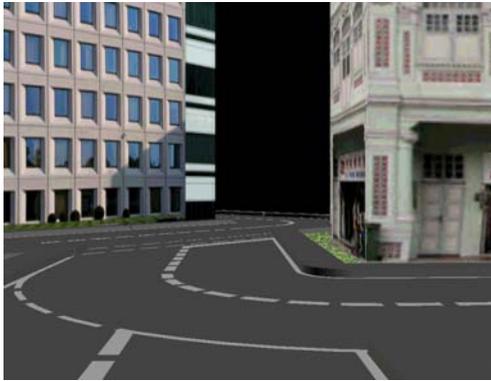
Thus, this seems to be a promising solution for the problem of providing depth perception for all distances, mentioned above. But the effect of the hyperfocal distance refers to film and photography and cannot be mapped to the visual system of humans. This means if it would be possible to use this effect within the optical setup of a head-up display, the depth of field which is perceived by a human, depends finally on the lens and the aperture of the eye. Especially, because different lightning conditions force the human eye to close or open its aperture, an universal solution suitable for all external conditions is difficult to realize.

C Pictures

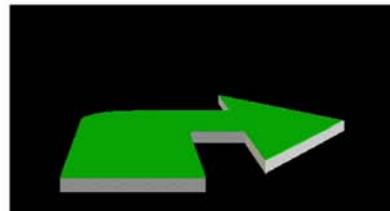
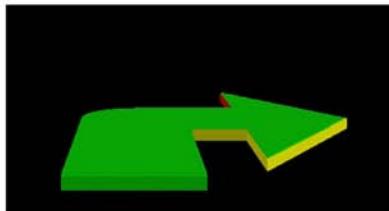
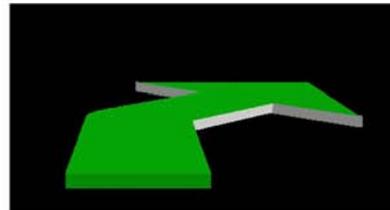
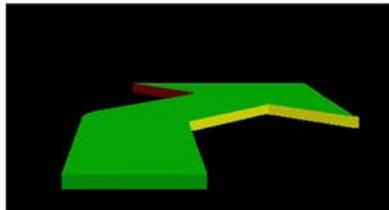
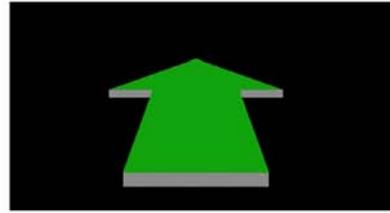
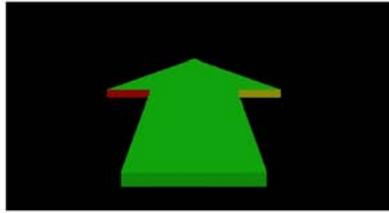
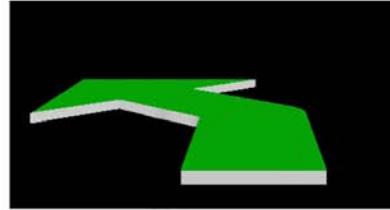
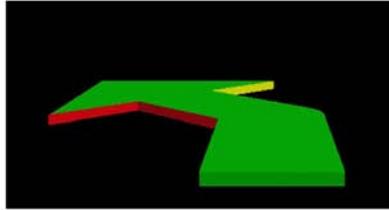
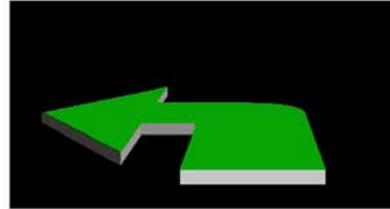
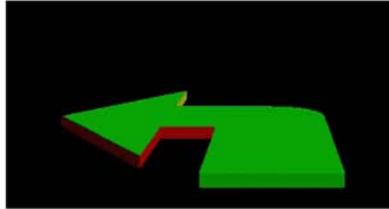
C.1 Virtual World



C Pictures



C.2 Navigation Arrows



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