

# A Survey of Challenges Related to the Design of 3D User Interfaces for Car Drivers

Marcus Tönnis\*  
Technische Universität München  
Fakultät für Informatik  
Boltzmannstraße 3  
85748 Garching b. M., Germany  
Tel/Fax: +49 89 289 17083 /-17059

Verena Broy†  
BMW Forschung & Technik GmbH  
Hanauer Straße 46  
80992 München  
Tel.: +49 (0) 89 382 48916  
Fax: +49 (0) 89 382 44988

Gudrun Klinker‡  
Technische Universität München  
Fakultät für Informatik  
Boltzmannstraße 3  
85748 Garching b. M., Germany  
Tel/Fax: +49 89 289 17083 /-17059

## ABSTRACT

After successfully integrating desktop-based concepts into drivers' cockpits, it is now time to investigate options towards integrating 3D user interaction techniques. Such interaction techniques are becoming increasingly important to handle the ever-growing wealth of information that cars can provide to their drivers regarding traffic, road and car conditions, as well as entertainment and communication facilities. However, since drivers have to focus primarily on the road, they cannot lend their full attention to the user interface. Thus, common requirements and rules for interface design need to be extended. In this paper, we present and discuss the implication of such constraints on 3D user interfaces, listing some upcoming options for integrating 3D interfaces into cars.

In addition, we present the concept that cars are no longer mainly mechanical objects. Rather they are complex computer systems with very particular input and output devices and mobile functionality. Following this new view, we reconsider familiar control devices of cars, such as the steering wheel and the gas and brake pedals as input and output devices to a very special three-dimensional computer application with strong connections to the real environment. In this light, such interaction devices serve as valuable examples of well-designed 3D user interfaces for computer-based navigation.

**CR Categories:** H.1.2 [Models and Principles]: User/Machine Systems—Human Information Processing; H.5.2 [Information Interfaces and Presentation]: User Interfaces—Ergonomics;

**Keywords:** Usability, Car, Augmented Reality, Taxonomy, Ergonomics

## 1 INTRODUCTION

### 1.1 Current Situation in Man-Machine Interaction in Cars

Today's cars provide an increasing number of new functionalities that enhance the safety and driving performance of drivers or raise their level of comfort. Passive safety systems such as airbags were among the first to be integrated. More recently, systems for active cruise control [4] have been added, addressing aspects of active safety and directly influencing the driving process itself. Further systems, such as night vision, will extend the drivers' sensing capabilities. In addition, information systems of general interest have become increasingly common, providing luxury facilities or enabling modern communication mechanisms. Examples are restau-

rant guides, navigation systems, individual music collections, email and internet services. With every new generation of cars, there are more built-in functions.

There is a limit to the number of control buttons that can be provided in a car to directly control individual functionalities. Since the late 90's, it has become necessary to decouple the number of functions from the number of direct interaction devices. Some approaches, such as the BMW iDrive [7, 30] have reduced many of the input and output devices down to a single multifunctional controller and a hierarchical menu structure. This approach has been adopted from the computer domain.

Yet, menu structures of computer applications cannot be mapped one-to-one into the car domain. The need to combine interaction tasks with a dominating driving task is an extension to the common requirements and rules for interface design. Users must always be able to switch their attention back from system interactions to the *primary driving task* in a car. ISO-Standards [12, 13] state various compliance procedures for in-vehicle visual presentations and principles for dialogue management. They lead to strong requirements for Man-Machine-Interfaces (MMI) in cars. Current car models provide menu-based systems that satisfy those requirements.

### 1.2 Available Concepts in the 3D User Interaction Community

We are investigating which novel 3D user interaction paradigms from the computer domain can be mapped under which conditions into the more restrictive automotive domain. To this end, we review all aspects of 3D user interfaces regarding the environment, the interior and the interaction in cars.

Recently, quite a number of three-dimensional user interfaces have been systematically analyzed and categorized w.r.t. computer applications in purely virtual environments [8]. As user interfaces are becoming more diverse and ubiquitously available, it is time to discuss their relevance to man-machine interaction in cars.

New display technologies, such as the BMW Head-Up Display (HUD) [5], allow the presentation of information within the driver's windshield. Yet, real-world information is competing severely with virtual HUD visualizations: If displayed virtual information occludes imminent information of the real world, or if the driver's perception is reduced due to too much virtual information, the driver's recognition of danger is reduced.

Upcoming input techniques, such as speech and gestures, allow the use of modalities that are not as directly associated with the driving task in the visual channel. It remains to be determined whether these new methods make graphical menus and their manipulation unnecessary, and whether they generate no - or just minimal - influence on the driver's capabilities. Ranney [23] has shown that a voice interface can help to reduce the peripheral interference but not the attentional interference. Also these innovative interactions generate interference with the driver's perception.

\*e-mail: toennis@in.tum.de

†e-mail: Verena.Broy@bmw.de

‡e-mail: klinker@in.tum.de



Figure 1: Head-Up Display in a BMW 5 series, courtesy of [6]

### 1.3 Our Approach: The Car as a Complex Embedded 3D Computer System

In this paper, we combine our discussion on general concepts of 3D user interaction with the thesis that cars are no longer mainly mechanical objects. Rather they are complex computer systems with very particular input and output devices and mobile functionality. Following this new view, we reconsider familiar control devices of cars, such as the steering wheel and the gas and brake pedals as input and output devices to a very special three-dimensional computer application with strong connections to the real environment. In this light, such interaction devices serve as valuable examples of well-designed 3D user interfaces for computer-based navigation.

We base our discussions on experiences in an ongoing research project towards creating and evaluating novel visualization and interaction schemes for car drivers w.r.t. requirements of safety, increasing complexity and the current state of standards. Complementary to our detailed bottom-up investigations of diverse specific issues in this project, this paper discusses general principles of the design of those interfaces in a top-down manner.

This paper provides a survey of classifications of interaction domains. It discusses the use of common 3D interaction techniques in cars. We report on our findings regarding the design of 3D user interfaces in cars. The paper provides guidelines regarding the amount and the spread of 3D user interfaces across a driver's cockpit and discusses their cognitive interference. We start with a survey of the requirements of user interfaces in the automobile domain. Afterwards we give detailed explanations for the area of input, output and interaction techniques. Finally, we summarize our findings.

## 2 CONSTRAINTS OF AN AUTOMOBILE ENVIRONMENT

Automobile environments impose high requirements on the design of user interfaces. When users are driving a car and interacting at the same time with a system, driving constitutes a highly complex primary task that needs a significant amount of their attention. Driving skills are automated to some extent. Since driving school, drivers' skills increase considerably such that they require less cognitive load. Thus, users are, in fact, able to handle additional tasks. Yet, due to safety issues, secondary in-car interaction systems have to be extremely user centered.

In this section, we decouple the driving task from the interaction task in order to provide a clear description of the conditions of this problem domain. Nielsen's definition of usability [19] can be transferred into the car: Learnability, efficiency, memorability, errors and satisfaction are important factors that must be considered. A novel criterion, specific to automotive settings, is the extent to which a driver is distracted from the driving task.

## 2.1 Interaction in Cars

### Primary, Secondary and Tertiary Tasks

Interactive tasks in cars can be divided into three classes: primary, secondary and tertiary tasks [16]. *Primary tasks* describe how to maneuver the vehicle itself. The driver controls heading and speed of the car, as well as the distance to other cars or objects. *Secondary tasks* are mandatory functions such as setting turning signals and activating the windshield wiper. They increase safety for the driver, the car and the environment. *Tertiary tasks* cover entertainment and information functionality. These do not have any direct relationship to the driving task. Rather, they provide luxury services which are in high demand from today's car buyers, and thus a mandatory asset in modern cars.

Figure 2 illustrates how primary, secondary and tertiary tasks can be placed in physically separate areas of the cockpit. Since primary tasks focus on direct interaction with the outside world, information from such tasks is best shown in the windshield (HUD). Users control primary tasks via devices (gas pedal, steering wheel) that are in a comfortable distance for arms and legs – the anthropometric distance. Secondary user interfaces should by majority remain in a distance that is still easily reachable and that is close to the focal perspective of the driver. Here, the area around the steering wheel below the windshield suits well. Tertiary functionality is placed next to the secondary area more to the center of the car. There it is still accessible, but it does not interfere directly with the area most relevant to car driving.

Exceptions can be granted for functionality that is used very often. Access to this functionality must be provided immediately. It is better to place such functionality within the area of the primary or secondary region. Therefore, this layout of interactive regions also depends on the frequency of usage.

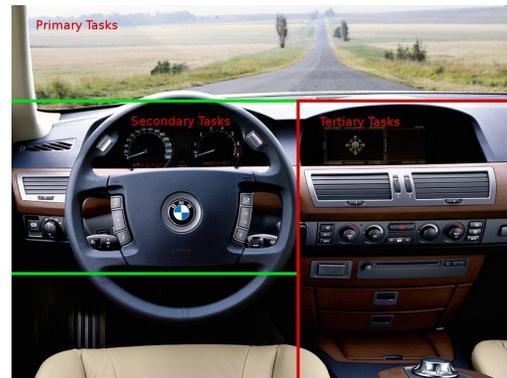


Figure 2: Distribution of primary, secondary and tertiary tasks

### Driver Information Systems versus Driver Assistance Systems

Driver support systems can be categorized based on their goals towards comfort and safety. We distinguish between driver information systems (IVIS<sup>1</sup>) and driver assistance systems (ADAS<sup>2</sup>). *Driver information systems* are designed to inform and entertain the user while driving. Examples are air condition control, radio control and car navigation systems. *Driver assistance systems* explicitly support drivers with their driving task. Examples are heading control or distance control (ACC) [4]. They do increase the comfort of driving. Yet, they are primarily designed and introduced in cars in order to enhance active safety.

<sup>1</sup>In-vehicle Information Systems (IVIS)

<sup>2</sup>Advanced Driver Assistance Systems (ADAS)

### Cross-Relationships

Information systems are closely associated with tertiary tasks. Driver assistance systems cannot be assigned that easily to tasks. When drivers provide input to an assistance system, they interact within the secondary area, because the minimum requirements of common maneuvering are already fulfilled by the steering wheel and the pedals. Yet, the feedback from assistance systems is inherently tied to the primary driving task – in particular if the car has means to actively control the pedals and the steering wheel. For instance, the Active Cruise Control (ACC) system of BMW actively decreases the speed of a car, when a slower car is at close distance in front. Drivers notice the decreased speed from kinesthetic cues. Nevertheless BMW car drivers are able to overrule every intended action of a car.

## 2.2 The Task of Driving

The driving task can be presented with respect to global awareness and local guidance [29]. *Global awareness* pertains to knowledge regarding the route to the destination. It requires large scale knowledge associating streets and distances, as taken out of a map.

*Local guidance* includes tasks that involve controlling the vehicle and knowledge about the environmental situation. Dealing with local guidance means keeping the car on the road and not hitting other cars or obstacles. Drivers have to know about the exact spatial relationships of their near environment. Whenever drivers use local guidance, they control the steering wheel and the pedals.

The task of driving is, in itself, performed within the real world. As the speed of motion in real cars generally is rather fast, the driver's cognitive load is focussed on dealing with that real, three-dimensional world.

## 2.3 International Standards

The question how to combine the driving task with interaction tasks generates novel interaction issues.

During past years, computer technology has entered automotive systems, and ISO standards (EN ISO 15005:2003 [12] and EN ISO 15008:2003 [13]) have been established to give recommendations on the interaction design aspects and to enforce them. ISO states the following principles to be important.

Transport information and control systems must be suitable for use while driving. They have to be applicable to tasks related to transport information and to the control system (TICS). Furthermore, they must be convenient for the driver.

In-vehicle systems should not distract the cognitive skills of drivers. Drivers have to react primarily to the current driving situation – even when they are interacting with the system. The driver must always be in charge. He shouldn't ever take both hands off the steering wheel to provide input to the system.

Some more issues that are especially enforced by the driving task are timing – presenting information in small, understandable pieces – interruptability and the requirement for no continuous visual attention as well as immediate reaction and conformity with driver expectations. Common issues such as simplicity, consistency, controllability, self-explanation and fault-tolerance are further important requirements for interactive systems in cars.

## 3 INPUT

Similarly to Bowman [8], we define input devices as physical tools used to implement various interaction techniques. In this section, we distinguish between input devices for primary, secondary and tertiary tasks in a car, according to general design guidelines. At the end, we outline interdependencies between various input modalities.

## 3.1 General Design Guidelines

A number of general requirements exist which restrict the options of three-dimensional user interfaces in cars: Input facilities in cars cannot request drivers to take both hands simultaneously off the steering wheel. User input should require as little visual attention as possible and should not require an explicit learning phase. It must be fast and easy for drivers to understand the underlying functionality of an input device, such that the driver does not have to think long about the process of telling the car what he wants the system to do. Focussing the driver's thoughts onto understanding something new, such as a new input device or its relationship to other functionality, could lead to a loss of attention to the environmental situation and could therefore contribute an accident. Furthermore, it is important for drivers to be able to act without supplementary equipment. Thus, input devices, such as data gloves or ring mice are not suitable. All input devices that require use of both hands, such as two handed joysticks and tablet computers, are not acceptable.

## 3.2 Primary Devices

Primary devices are devices that have direct influence on controlling the heading and speed of the car. Usually, these are the steering wheel and the gas and brake pedals. They must have a direct one-to-one mapping to their functionality, without a chance of being in a wrong input mode. In addition, they must generate immediate feedback whenever they are used.

Maneuvering a car is a task that highly depends on 3D relationships between the own car, other cars, and the environment with all its obstacles. An intuitive mapping between the shape, the degrees of freedom and the associated action must be kept, in order to generate no secondary incompatibility [9] which could cause ambiguity w.r.t. their use. For example, rotation of the steering wheel transforms directly and uniformly into car rotation.

## 3.3 Secondary Devices

Secondary devices are used to control mandatory functionality such as turn signals and windshield wipers. This functionality is not directly associated with the driving task, but it is mandatory in order to keep or improve the safety of the driver, the car and the environment. Since secondary tasks are not as important as primary tasks, immediate accessibility does not play such a fundamental role. Direct access should be granted, but access to the devices must not be as direct as for primary controls.

## 3.4 Tertiary Devices

Tertiary devices serve entertainment and information functions. They do not have a direct relationship to the driving task itself or to safety issues. Since there is no such direct relationship, immediate and direct access is not necessary.

In every new generation of cars, new functionality is introduced. For example, there are more than 700 tertiary functions [7] implemented in the current BMW 7 series. Since traditional approaches, such as a one-to-one mapping between button and function, have proven to be insufficient at the end of the 20th century, a paradigm shift has recently been introduced. Nowadays, multi-functional controllers provide generalized access to the huge amount of functionality. For instance, the BMW iDrive [7, 30], the Audi MMI [3] and the Mercedes COMMAND system [11] are controllers that provide access to all tertiary functions in a unified way (see Fig. 3). These controllers don't offer many directions of motion and rotation since such diversity could result in ambiguity concerning the use of the controller.



(a)



(b)



(c)



(d)



(e)



(f)

Figure 3: Menus and Controllers - a, b: BMW - c, d: Audi - e, f: DaimlerChrysler

Usability and acceptance decreases when all functionality must be accessed via these multi-functional controllers. Direct access should still be granted for the most recently used functions. The use of controllers may be most suitable for providing continuous as well as discrete input.

### 3.5 Upcoming Speech and Gesture Input

Speech input seems to be a suitable mode of interaction in a car. But it is not the answer for all problems that arise in an automobile environment. Despite the fact that speech uses a nonvisual channel, visual attention is affected by speech input. Plangger et al. [22] showed that users need a physical reference point to understand whether the system understood their spoken input or not. Often, drivers look at a point in the instrument cluster while and shortly after speaking. In addition, speech recognition in cars has the same problems as in other VE environments [8]: poor speech recognition systems and missing strategies for segmentation.

## 4 OUTPUT

With regard to human senses, output can be classified into visual, auditory, haptic and olfactory displays [8]. We discuss findings and issues concerning these displays w.r.t. to their use in cars and consider their multi-modal combination.

### 4.1 Visual Displays

Visual attention is crucial for driving. It is the main input channel for maneuvering a car. Thus, it must be handled very carefully. Drivers must be able to retract their visual attention from optical displays to the driving task any time.

To this end, displays of instruments which are most important for driving are located in the secondary sector (see Fig. 2). Most of them are currently analog displays providing well defined output

such as the current speed or the current oil temperature. Bulbs and Light Emitting Diodes (LEDs) indicate activity of further functionality like the turn signal or lights.

Monitors and projecting displays have high potential for being used in cars, since they can present information more dynamically dependant on the current situation. But they have to be well positioned. Drivers need to be able to look at them without problems. They may not be placed more than 30 degrees below a driver's horizontal viewing direction [15]. Placing a display too low inside the car would require drivers to turn their heads and eyes too much, thereby increasing the overall glance time. In the current setup of cars, there are two regions where displays can be placed: directly in front of the driver behind the steering wheel or to the right of the steering wheel in the tertiary sector. All other regions either have the potential of being occluded by the driver's or co-driver's arms, or they are obstructing the driver's view through the windshield. To date, central information displays (CIDs) have been integrated into car models of many manufacturers. They typically present tertiary information content. View control is provided via hierarchical menus.

3D virtual environments provide many more visual display options, such as large workbenches and surround screens. Such devices are not suitable for in-car use due to the limited space, and because they draw too much visual attention, thereby distracting drivers from the driving task. Concepts, such as fully immersive virtual reality displays are not applicable since they would occlude the reality. As mentioned before, drivers must be able to drive and interact with additional systems without use of supplementary equipment. For this reason it is not possible to integrate video-based head mounted displays. A technical failure could have fatal consequences.

In contrast, semi-immersive approaches have high potential. In the BMW 5 series, a head-up display (HUD) presents information on the windshield. It is arranged close to an average driver's horizontal line of sight and shows speed, distance and navigational information (see Fig. 1). Other companies are also in the process of introducing HUD technology [27]. One of the promising advantages of HUDs is the shorter glance time, because the driver's eyes only have to turn minimal amounts. Since HUDs are designed to project information to a position 3 meters in front of the windshield, the accommodation time for drivers is faster than when they need to focus on displays in the dashboard at a distance of approximately 50 cm. Currently available HUDs provide a field of view of approximately 6 degrees. Therefore, they can display only very limited amounts of information, such as the current speed or icons representing navigational arrows. The importance of HUDs in cars will grow significantly, as soon as it is technically feasible to project large amounts of information in high resolution onto the windshield. Technology to track a driver's eyes will enable Augmented Reality (AR) to embed dynamic illustrations into the environment, thereby minimizing glance distraction time. For instance, when virtual navigational arrows are placed onto the road in front of the car, drivers don't have to look at the car-internal navigation display. Another example uses AR to guide the driver's attention to the direction of an imminent danger [26, 14]. But this upcoming technology generates new questions and problems pertaining to information overload, perceptual tunneling and cognitive capture.

**Information Overload** refers to the state of having too much information to make a decision or remain informed about a topic. Large amounts of currently available information, a high rate of new information being added, contradictions in available information, a low signal-to-noise ratio, and inefficient methods for comparing and processing different kinds of information can all contribute to this effect.

**Perceptual tunneling** is a phenomenon that originally comes from aviation and in which an individual becomes focused on one

stimulus, like a flashing warning signal and neglects to attend to other important tasks/information such as driving the car.

**Cognitive capture** refers to the situation where the driver may be totally "lost in thought," a condition which, in particular, could impair situational awareness. Where emotional content (i.e., personal involvement) in a conversation is high, such as arguing with someone over the phone, the likelihood of cognitive capture is increased. Instruments that require some level of cognitive involvement and thereby could lead to a loss of situational awareness are viewed as increasing the risk of a crash.

When embedding additional visual information into the real world, information density is not computable anymore, because the outside environment of the car is changing during travel. If many events that are relevant to driving occur at the same location of the windshield, they can generate one or more of the announced problems.

## 4.2 Auditory Displays

Auditory displays provide an attractive second communication channel, reducing the load on the visual channel. Minimal interference with the visual channel do occur since some attention is drawn to the perception of the acoustic signals.

The auditory channel can be used to issue informational or alarm signals and for speech based communication. Alarm signals are given, for instance, when the environmental temperature is below a certain threshold or when the ACC works outside its operating range (too high or low driving speeds) and thus turns itself off. Such sounds inform the driver about a contextual change that can have influence on the car's safety. Sounds can be directionally encoded to provide spatial cues. In this respect, 3D sound displays have the potential to support drivers in locating objects in the environment, thereby warning drivers about imminent dangers of collision. For example, an older version of BMW's parking assistant provided warning sounds from corners of the car close to nearby obstacles. The use of auditory warnings is promising because they immediately capture a driver's attention. On the other hand humans have problems distinguishing between many different pitches. Therefore we suggest to use sounds just in situations of an alert, where immediate attention of the user is required. An auditory hint can inform about the direction of the danger and further information could be provided in another modality.

Speech based communication (input and output) is most often used for tertiary interaction, e.g. for menu selections or other user actions. Speech output can also be used as feedback to actions that have not used speech input. It can be helpful when large quantities of information (texts) have to be conveyed to the driver. Examples are incoming messages: SMS or electronic mail.

However, there are limitations to the use of auditory displays. Some types of information are transmitted faster and more understandably in a visual representation. Spatial information, such as distances to environmental obstacles, is generally easier to perceive visually than aurally. Due to the sequential nature of spoken words, such continuous information is easier presented in the visual channel. In addition, the use of different sound frequencies can result in inaccurate interpretations. Furthermore auditory output interferes with the driving capabilities to a certain degree. When auditory output is given just when a difficult driving situation occurs, the driver's attention can be captured by the acoustic output and the imminent danger might go unnoticed. We do not recommend speech output for warnings and alerts. Warning sounds have to be understood immediately, but in case of speech output, the driver has to listen to the whole notification. Sound output quickly becomes annoying since it disturbs other auditory activities like music or conversations. Furthermore, drivers may feel embarrassed, if comments on driving mistakes are overheard by fellow passengers.

## 4.3 Haptic and Tactile Displays

Haptic and tactile output are interesting for in-car applications, because they do not need visual attention and they are user-centered. Most likely, haptic output is not suitable to convey complex information, but it is predestinated to catch the driver's attention. Citroen realized a haptic concept in a lane departure warning system called LDWS [10]. When the vehicle moves across road markings without the indicator being used, the system warns the driver with a vibrating signal on the left or right side of the driver's seat, depending on the direction in which the vehicle is drifting. When the driver feels the vibration in his back, he almost has the same feeling as if the car was losing contact to the ground.

DaimlerChrysler [18] examined how well auditory and haptic alert modalities affect drivers' perception of collision warnings when the car ahead of them unexpectedly brakes. One of their experiments found that haptic alerts, in this case also a vibrating seat, were perceived as less annoying and more appropriate.

Primary and secondary tasks of driving provide further potential usage of haptic feedback. To help drivers stay within speed limits, the according position of the gas pedal can be marked as a pressure point – similar to the "kick-down" point for controlling an automatic transmission gearbox. Warnings regarding deviations from the center of the lane can be indicated by forces or vibrations transmitted via the steering wheel.

Haptic feedback is also suitable for the tertiary sector. When long lists have to be searched in a menu, the controller can be locked w.r.t. to the direction of motion when the end of the list is reached. The integration of touch-displays allows direct feedback. Tactile displays can also give feedback about the position and the state of pressure of buttons on a touch display.

## 4.4 Multimodal Displays

Multimodal interfaces combine the advantages of different output modalities to overcome individual weaknesses. An example is the parking assistant of BMW. Its initial, purely auditory version did not optimally support the estimation of the distance to nearby objects. It was much improved by adding a visual component that presents a bird's eye overview of the car and the sensed close-by environment, highlighting obstacles in warning colors.

# 5 INTERACTION TECHNIQUES

According to Bowman [8], interaction techniques are methods used to accomplish a given task via the existing interface. Since interaction techniques are strongly related to the goals and tasks of a system, we distinguish between interaction techniques for the driving task itself, driver assistance systems (ADAS) and in-vehicle information systems (IVIS). We discuss all methods with respect to these systems and their relationship to primary, secondary and tertiary tasks in a car.

## 5.1 Manipulation

Manipulational tasks can be divided into selection - acquiring a particular object from a set of objects, positioning - moving the object to another location and rotation - changing the orientation of an object [8].

### Manipulations while Driving

Driving is an interactive task in itself. Since driving is the primary automotive task and since it is associated with real danger, manipulators that are relevant to this task are physical rather than virtual.

Drivers change the orientation of a car by turning the steering wheel, which thereby controls one degree of freedom. Steering manipulations can be mapped isometrically to the real behavior of the car: a right rotation of the steering wheel corresponds to a right turn of the car.

The position of a car is manipulated by pressing or releasing the gas pedal or the brake pedal. In this setup, every pedal has its own degree of freedom. Yet, together, they control only one degree of freedom. The gas pedal provides an isometric mapping from foot position to car motion. The deeper the pedal is pressed, the faster the car goes. The brake pedal works inversely. The more the pedal is pressed, the slower the car gets. Drivers need to envision a higher order technical concept to obtain a compatible intuition for this manipulation: The stronger the force on the break pedal, the higher the braking force. We have a case of secondary incompatibility [9] where input is not directly compatible with the desired result. This higher level of abstraction needs to be experienced and acquired by novice drivers when they learn to drive a car. Alternative approaches have been researched, such as steering with a joystick [25]. Manipulations should directly reflect their influence on car dynamics.

Additional interactions with other in-car systems should provide manipulation metaphors that do not reflect spatial relationships. Otherwise the driver would have to switch or transform between both frames of reference.

#### **Manipulations for Driver Assistance (ADAS)**

Driver assistance systems provide additional support for the driving task. Examples are automatic distance control and heading control. A well defined assistance system panel is needed that can easily be distinguished from luxury devices. Assistance functions influence the driving task itself in changing the position and orientation because of contextual information. Sensors are scanning the environment around the car and the assistance systems react to these information. The heading control e.g. changes the orientation of the car and is therefore altering the rotation.

To date, manipulation and control of driver assistance systems is provided by physical devices. Information showing the current state of these systems, and devices for manipulating their state are placed in the primary or secondary area of the cockpit (Figure 2). Longer-term concepts consider presenting distance information three-dimensionally in the HUD and using gaze-based pointing [21] in combination with speech to select and alter system parameters.

#### **Manipulations for Driver Information (IVIS)**

Input devices for driver information systems are placed in the tertiary area as shown in Figure 2. At the moment some car manufacturers provide additional softkeys for favorite functions on the steering wheel. In general, information systems do not have a relationship to the environment around the car and do not take direct influence on the driving task. The luxury and information functions are manipulating the situation inside the car, e.g. controlling the temperature or the sound volume. Additionally, they inform and entertain the driver. Manipulation involves selecting functions in menus and changing options – e.g. to change audio settings. To date, they use abstract, menu-based manipulation metaphors. Since well known menu hierarchies have two dimensional characteristics, rotational manipulation can be used for positioning a focus onto a specific function.

Input devices in cars require interruptability of every additional input procedure in short intervals such that drivers can reorient their attention to the driving task.

## **5.2 Travel**

Bowman defines travel as the motor component of navigation. It defines the actions that are performed to move users from their current location to a new target location or in a desired direction.

## **Maneuvering the Car (ADAS)**

Travelling is similar to Wang's definition of local guidance [29]. For the task of driving, this means to manage the car motions through the actual (real) environment. In this respect, the process of turning the car is divided into a series of small actions: activate the turn signal, slow down, look into the mirrors, look over shoulder, turn the steering wheel with the appropriate angle and operate the gas pedal. Maneuvering requires both primary and secondary tasks. Therefore, interaction with all of these primary and secondary controls must not interfere with one another.

Interaction with driver assistance systems interferes with the task of driving – in particular when such systems, when activated, enhance driving performance. Interaction time has to be as short as possible. Generally, interaction with assistance systems should be provided by use of on/off-switches. Easy selection concepts for configuring parameters require dedicated devices. The use of dedicated devices ensures that no modes have to be changed.

## **Navigating in Information Systems (IVIS)**

Information systems use menu structures in the central information display (CID) and a multifunctional control knob (iDrive, [7]) to allow drivers to select and modify settings. Alternatively, input can be provided by speech. Travelling in menu structures requires users to know how the multifunctional controller is implemented, or how to access certain functions via voice. The structure of the menus must be extended with indicators describing the proper use of the controller, e.g. presenting a rounded shape, when the controller has to be turned and a rectangular shape when the knob has to be pressed. If additional keys exist which provide direct access to a subset of functionality (such as a radio menu), these must be labeled. If those keys are configurable softkeys, a visual feedback must be given that uses the same orientation as the layout of the keys.

## **5.3 Wayfinding**

Wayfinding is the cognitive process of learning and understanding a path through an environment. The wayfinding task is to know how to get from a starting point to a desired destination. As in the previous sections, we discuss this concept in relationship to techniques regarding car assistance systems (ADAS) and information systems (IVIS).

### **Knowing the Route to a Destination (ADAS)**

This part of the cognitive component can be mapped to Wang's definition of global awareness. When drivers are approaching a crossing, wayfinding enables them to know whether to go right, left or to keep the direction. It is important whether drivers know a certain route or whether they drive it for the first time. In the latter case, a higher workload is necessary since they have to build up a cognitive map of the environmental spatial relationships [17].

The amount of knowledge about a route has implications on the degree of interference between primary and tertiary aspects of driving. If drivers know the route to their destination, they can focus on the primary driving task and fulfill the secondary functions. If they do not know the route, they may want to request assistance from a navigation system. The driver implicitly interacts with a navigation system by driving his car. Car motion is sensed by the navigation system via GPS, resulting in an update to the current state of the car. Feedback from the navigation system to the driver is generally provided both via the optical and the auditory channel: A bird's eye view (map) of the car and its current surroundings are presented (at a suitable scale) in the central information display (CID). Furthermore, speech instructions tell the driver how to proceed through a crossing. As an improvement, navigational arrows can be presented in the head-up display (HUD), thereby minimizing glance times, reducing ambiguities and enhancing driving performance.

### Knowing where to find Functionality (IVIS)

Driver information systems are currently typically organized in hierarchical menu structures. Wayfinding means that drivers have to internalize this menu structure, knowing how to get to a particular (sub)menu when they want to change settings.

To some extent, the wayfinding task in in-vehicle information systems is relatively similar to wayfinding in the driving task: Drivers have to build up cognitive maps of an unknown environment over time. Currently, we assume that it is not practicable to design a 3D spatial interface for wayfinding functions in tertiary menu structures. Interaction techniques both with respect to primary road navigation and with respect to tertiary menu control would have to share the same valuable cognitive resources. This could generate interference with the driving task because the same cognitive capabilities are requested.

Since the configuration of information systems is not a safety-critical issue, it is not important that the driver has immediate access to specific tertiary functionality the same way as to a primary function. The access path to functionality can therefore be longer – as long as it is interruptible. Yet, it is important to ensure that drivers can easily build up a clear cognitive model of the system, helping them to remember paths to specific functionality.

### 5.4 System Control

In System Control tasks, users issue abstract, non-spatial commands to request the system to perform a particular function, to change the mode of interaction or to change the system state.

Abstract concepts of system control are not suitable to tasks involving car driving. They may, however, be amenable to driver assistance systems (ADAS). Such systems require abstract settings – e.g. to adjust reactions to distance measurements to the car ahead in the active cruise control system (ACC). In today's cars, assistance systems are isolated from other car functionality – thereby ensuring fast and direct access. However, as a consequence, drivers have to adjust functionality separately for different system components. To date, drivers receive a minimal amount of visual feedback to recent adjustments. The question is, if it is reasonable to provide systematic system control output presented as graphical menus, voice commands or gestural commands. With technical progress enabling more and more assistance systems, it seems not to be feasible for long to provide individual system feedback to individual system adjustments. There will be a need to think about suitably integrated system control techniques for driver assistance systems.

In-vehicle driver information systems (IVIS) provide a large amount of information and functionality. Major car manufacturers have undergone a paradigm shift from traditional one-button-for-one-function approaches to integrated concepts. Nowadays, driver information systems are integrated in a graphical menu and are operated by a multifunctional controller. However, such approaches are not yet well accepted in the academic world for several reasons [20]. Firstly, current interaction schemes are strictly hierarchical and text-based – a concept that is easily understood by technical engineers, but not by non-technically oriented users. Furthermore, only few well known widgets of personal computer applications were implemented as checkboxes, lists and control checkers. Some attempts at improving the usability of such systems exist – e.g. by trying to integrate widgets like pull-down menus, bookmark functions and short cuts to get a networking structure [1]. A browsing metaphor may help drivers to use parallel menus [24]. Yet, it may be necessary to investigate new interaction approaches with strong metaphors, which are suitable to drivers' recognition knowledge, if they are suitable to the requirements for interaction systems in cars.

Today, several functions can be set by voice commands. This is a first step. Yet, voice recognition systems principally have the same problems as optical recognition and segmentation. The dialog via

voice is independent of the graphical menu. It has to be discussed whether an integrated multimodal approach with both graphical and voice input is more efficient than two parallel, separate interaction modes.

At the moment, there are no gestural commands implemented in cars. Althoff et al. showed that it is possible to integrate them and that it is possible to realize several meaningful gestures like yes, no, abort, back and forward to operate the hierarchic graphical menu [2].

### 5.5 Symbolic Input

Users do symbolic input to enter symbolic information (text, numbers and other symbols) into the system.

It is not necessary to provide specific symbolic input facilities specifically for the driving task itself. Driver assistance systems (ADAS) do require symbolic input in some cases. The active cruise control system (ACC) needs a velocity specification for the desired speed. At this point in time, cars accept the actual speed of car while it is running. Drivers are allowed to make minor adjustments via some button-oriented input device – e.g. by turning a control knob. The favored distance can be set by a throttle, providing different spans. As a consequence, symbolic input is only supported on a very abstract layer.

In in-vehicle information systems (IVIS), symbolic input is very important for many so-called *infotainment* applications and cannot be obtained via other input channels as in the driver assistance system. The required input is diverse including many special nouns that require exact spelling – e.g. when names of destinations or telephone partners are to be specified. Current systems textual input is typically accept symbolic input via the controller (IDrive, [7]), requesting drivers to manually select each individual letter in a *speller*. Automatic name completion provides some amount of input support. Other approaches include bringing a QWERTY keyboard into the car, using a keyboard of a mobile telephone, and using handwriting recognition on a touchpad [28]. Voice could also be an adequate solution. Yet, at this point, speech recognition systems are not able to correctly understand the required large variety of nouns spoken by people in different dialects.

## 6 CONCLUSION

This paper presents an overview of the potential and the problems involved in bringing 3D user interfaces and interaction into automotive driving environments. This situation is very special because users are executing another task of higher priority – car driving – parallel to providing system input. As a result, only limited cognitive and motor capabilities are available for the interaction task, requiring an extension to the list of usability criteria: minimal distraction from the driving task.

The driving task has limited similarities to interaction with a computer system: Drivers provide input to cars via pedals and the steering wheel, and they receive output via spatial and kinesthetic cues. They are performing interaction techniques mostly by object manipulation – positioning and rotating –, traveling and wayfinding. It is essential to keep this workload in mind when designing user interfaces for in-vehicle interaction systems.

### 6.1 Findings

In-vehicle interaction systems can be categorized in systems for primary, secondary and tertiary tasks. Their goals are either to assist drivers in performing their driving task or to inform and entertain them with so-called driver information systems.

*Input* devices for primary tasks must be provided as simple one-to-one mappings. They have to be placed in adequate anthropo-

metric distances. Since secondary tasks are strongly related to the driving task, their input devices should be positioned next to the primary input devices to ensure fast access. Tertiary tasks are not relevant for basic safety. Therefore, their input devices can be placed in a comfortable distance. They should not interfere with primary and secondary devices. Exceptions can be made for frequently used or favorite functions.

Visual *output* has to be handled carefully since the driving task needs visual attention. New technologies, such as head up displays provide promising potential since drivers do not have to turn their heads or eyes to glance at a screen. Yet, they also bring up new questions, such as the effects of perceptive tunneling and cognitive capture. Auditive and tactile output does not demand visual attention. Nonetheless, there are technological problems as well as user interface-related ones. Multimodal approaches have high potential to provide adequate interaction systems.

User *interaction* while driving consists mostly of manipulating, traveling and wayfinding. To avoid interference between the driving task and system interaction, we recommend to keep manipulation, traveling and wayfinding techniques as simple as possible. Since the driver's cognitive load is already high due to driving, additional high workloads complicate these interaction techniques.

In this paper, we have mapped all aspects of 3D user interfaces into automobile environments that consist of primary, secondary and tertiary tasks and are divided into driver assistance and information systems.

## 6.2 Future Work

Our future work will investigate issues regarding the use of HUDs and haptic feedback improved understanding of dangerous situations. Furthermore we are exploring concepts to display large amounts of information in depth based graphical structures rather than in menus.

It remains to be analyzed whether and how such concepts can improve driver performance and safety. We will perform evaluations in cooperation with Christian Lange from the Chair for Ergonomics of the Faculty of Mechanical Engineering. Currently we would like to thank him for providing answers to ergonomical questions.

## REFERENCES

- [1] M. Ablassmeier, G. Niedermaier, and G. Rigoll. A new approach of using network dialog structures in cars. In *8th World Multiconf. on Systemics, Cybernetics and Informatics*, Orlando, USA, Jul. 2004.
- [2] F. Althoff, R. Lindl, L. Walchshäusl, and S. Hoch. Robust multimodal hand- and head gesture recognition for controlling automotive infotainment systems. In *VDI: Fahrer im 21. Jahrhundert*, November 2005.
- [3] Audi. MMI Simulation Homepage. [http://www.audi.com/audi/com/en1/new\\_cars/technology/research/electronics\\_centre.html](http://www.audi.com/audi/com/en1/new_cars/technology/research/electronics_centre.html).
- [4] BMW. ACC. <http://www.bmw.co.za/products/acc/default.asp>.
- [5] BMW. Head-Up Display Homepage. <http://www.bmw.co.za/products/hud/default.asp>.
- [6] BMW. Head-Up Display Homepage 2. [http://www.bmw.com/com/en/index\\_narrowband.html](http://www.bmw.com/com/en/index_narrowband.html).
- [7] BMW. iDrive Techniklexikon. [http://www.bmw.de/de/faszination/techniklexikon/index.html?content=http://www.bmw.com/generic/de/de/faszination/technology/lexicon/content\\_reload.html?articleUrlStartidrivearticleUrlEnd](http://www.bmw.de/de/faszination/techniklexikon/index.html?content=http://www.bmw.com/generic/de/de/faszination/technology/lexicon/content_reload.html?articleUrlStartidrivearticleUrlEnd).
- [8] D.A. Bowman, E. Kruijff, J. J. LaViola, and I. Poupyrev. *3D User Interfaces: Theory and Practice*. Addison Wesley, 2004.
- [9] H. Bubb. Systemergonomische Gestaltung. In *Ergonomie (Schmidtke, H., Editor)*, Hanser Verlag, München, 1993.
- [10] Citroen. C5. <http://www.citroen.com/CWW/en-US/TECHNOLOGIE/S/SECURITY/AFIL/AFIL.htm>.
- [11] Daimler-Chrysler. Mercedes S-Klasse Homepage. [http://www.mercedes-benz.de/content/germany/mpc/mpc\\_germany\\_website/de/home\\_mpc/passenger\\_cars/home/products/new\\_cars/s.class.html](http://www.mercedes-benz.de/content/germany/mpc/mpc_germany_website/de/home_mpc/passenger_cars/home/products/new_cars/s.class.html).
- [12] DIN Deutsches Institut für Normung. *Road vehicles - Ergonomic aspects of transport information and control systems - Dialogue management principles and compliance procedures*, Mar. 2003. Ref.No.: DIN EN ISO 15005:2003.
- [13] DIN Deutsches Institut für Normung. *Road vehicles - Ergonomic aspects of transport information and control systems - Specifications and compliance procedures for in-vehicle visual presentation*, Oct. 2003. Ref.No.: DIN EN ISO 15008:2003-10.
- [14] DuPont. The DuPont Wedge for Head-up Display illuminates safety, navigation and handling features. [http://www.dupont.com/safetyglass/en/newsEvents/hud\\_gm.html](http://www.dupont.com/safetyglass/en/newsEvents/hud_gm.html).
- [15] European Commission. *European Statement of Principles*, Jun. 2005. ESOP 2005.
- [16] G. Geiser. *Man Machine Interaction in Vehicles*. ATZ 87, 1985. pages 74 - 77.
- [17] R. Golledge. *Wayfinding Behaviour: Cognitive Mapping and other Spatial Processes*. John Hopkins University Press, 1999.
- [18] J. D. Lee, J. D. Hoffman, and E. Hayes. Collision warning design to mitigate driver distraction. In *Proceedings of CHI*, April 2004.
- [19] J. Nielsen. *Usability Engineering*. Acad. Press, 1993.
- [20] D. Norman. Interaction Design for Automobile Interiors. [http://www.jnd.org/dn.mss/interaction\\_des.html](http://www.jnd.org/dn.mss/interaction_des.html).
- [21] V. Novak, C. Sandor, and G. Klinker. An AR workbench for experimenting with attentive user interfaces. In *Proc. of ISMAR*, Arlington, VA, USA, Nov. 2004.
- [22] U. Plangger, A. Khosravi, and G. Helas. Einfluss von sprachlicher und haptischer Bedienung auf die Fahrleistung und das Blickverhalten. Master's thesis, Technische Universität München, Chair for Ergonomics, 2005.
- [23] T. Ranney, J. Harbluk, and I. Noy. Effects of voice technology on test track driving performance: Implications of driver distraction. In *The Journal of the Human Factors and Ergonomics Society*, 2005.
- [24] B. Ratkovic. Individualisierungskonzepte im Rahmen multimodaler Infotainmentsysteme. Master's thesis, TU Muenchen, 2004.
- [25] B. Spanner. *Einfluss der Kompatibilität von Stellteilen auf die menschliche Zuverlässigkeit*. PhD thesis, Technische Universität München, Chair for Ergonomics, 1993.
- [26] M. Tönnis, C. Sandor, C. Lange, G. Klinker, and H. Bubb. Experimental evaluation of an augmented reality visualization for directing a car drivers attention. In *Proceedings of ISMAR*, October 2005.
- [27] Siemens VDO. Die Straße stets im Blick: Farbige Head-up-Display vor Serieneinsatz. <http://www.siemensvdo.de/de/pressarticle2001.asp?ArticleID=09001iaa>.
- [28] Siemens VDO. EasyControl with handwriting recognition. [http://www.siemensvdo.com/press/releases/infotainment/2003/SV\\_200309\\_007\\_e.htm](http://www.siemensvdo.com/press/releases/infotainment/2003/SV_200309_007_e.htm).
- [29] W. Wang. *Human Navigation Performance Using 6 Degree of Freedom Dynamic Viewpoint Tethering in Virtual Environments*. PhD thesis, Univ. of Toronto, Mechanical and Industrial Engineering, 2004.
- [30] A. Zeller, A. Wagner, and M. Spreng. iDrive - Zentrale Bedienung im neuen 7er von BMW. In: *Elektronik im Kraftfahrzeug*. In *VDI-Berichte Nr.1646*, 2001.