**Design space for driver-based automotive user interfaces** [1]

Over the last 100 years it has become much easier to operate a car. However in recent years the number of functions a user can control while driving has greatly increased. Infotainment, entertainment and comfort systems as well as driver assistance contribute to this trend. Interaction with these systems plays an important role, as on one hand this can improve the user experience while driving but on the other hand it may distract from the primary task of driving. User interfaces in cars differ regarding the number of input and output devices and their placement in the car to a great extent. In this paper, we introduce a first design space for driver-based automotive user interfaces that allows a comprehensive description of input and output devices in a car with regard to placement and modality. This design space is intended to provide a basis for analyzing and discussing different user interface arrangements in cars, to compare alternative user interface setups, and to identify new opportunities for interaction and placement of controls. We present a graphical representation of the design space and discuss its usage in detail based on several examples. To assess the completeness of the proposed design space we used it to classify and compare user interfaces from more than 100 cars shown at IAA2007, cars from the BMW museum, and from the A2Mac1 image database.

# ****Writing to your car: handwritten text input while driving** [2]**

For in-car navigation, information and entertainment systems, text input is increasingly important. We investigate handwriting as a text input modality and assess where to best position the input surface and how to provide feedback. For this purpose, we created different prototypes that allow text input on the steering wheel and in the central console, as well as visual feedback on the input surface and on the dashboard. The results of the study indicate that handwritten text input on the steering wheel is well-received by the users and that the visual feedback should be presented in the dashboard area or on the steering wheel. We also observed that the number of corrective actions and the remaining errors were significantly smaller (25% less) on the steering wheel than in the central console and that entering text while driving made people drive slower.

# ****A multi-touch enabled steering wheel: exploring the design space** [3]**

Cars offer an increasing number of infotainment systems as well as comfort functions that can be controlled by the driver. With our research we investigate new interaction techniques that aim to make it easier to interact with these systems while driving. In contrast to the standard approach of combining all functions into hierarchical menus controlled by a multifunctional controller or a touch screen we suggest to utilize the space on the steering wheel as additional interaction surface. In this paper we show the design challenges that arise for multi-touch interaction on a steering wheel. In particular we investigate how to deal with input and output while driving and hence rotating the wheel. We describe the details of a functional prototype of a multi-touch steering wheel that is based on FTIR and a projector, which was built to explore experimentally the user experience created. In an initial study with 12 participants we show that the approach has a general utility and that people can use gestures for controlling applications intuitively but have difficulties to imagine gestures to select applications.

# ****Gestural interaction on the steering wheel: reducing the visual demand** [4]**

Cars offer an increasing number of infotainment systems as well as comfort functions that can be controlled by the driver. In our research, we investigate new interaction techniques that aim to make it easier to interact with these systems while driving. We suggest utilizing the steering wheel as an additional interaction surface. In this paper, we present two user studies conducted with a working prototype of a multi-touch steering wheel. In the first, we developed a user-defined steering wheel gesture set, and in the second, we applied the identified gestures and compared their application to conventional user interaction with infotainment systems in terms of driver distraction. The main outcome was that driver's visual demand is reduced significantly by using gestural interaction on the multi-touch steering wheel.

# ****The wheels are turning: content rotation on steering wheel displays** [5]**

The steering wheel is a promising space for the integration of displays since in the car there is very limited space for integrating interactive modalities for the driver that are close to the preferred field of view as well as in an easy to reach position. When the wheel is turned, the screen content could change its orientation to increase the readability and therefore reduce the distraction from the road. Thus, this paper describes three different content rotation behaviors for steering wheel displays. To investigate what effect these behaviors have on the driver in terms of visual distraction from the road we conducted a user study with eye tracking asking participants to read the current speed. We found no differences in terms of distraction and response time between the different rotation behaviors. Compared to a similar display in a dashboard position the visual distraction was reduced.

# ****Exploring the back of the steering wheel: text input with hands on the wheel and eyes on the road** [6]**

Safe interaction with interactive systems in the car requires both hands to be placed on the steering wheel and eyes to be kept on the road. To allow safe text input in the vehicle, we propose the back of the steering wheel as space for interactive text input elements. In the effort to explore this space, we present two design alternatives for text input elements; one has two sliding sensors and the other has three buttons on each side of the wheel. In combination with a head up display and an adapted keyboard layout, these elements allow text input while driving with the eyes on the road an the hands on the wheel. In a first study with end users, we show the potential of the proposed text input approach for future vehicles.

# ****Driver queries using wheel-constrained finger pointing and 3-D head-up display visual feedback** [7]**

With the capability of fast, wireless communication, combined with cloud and location-based services, modern drivers can potentially access a wide variety of information about their automobile's environment. This paper presents a system for information query by the driver by using a simple pointing mechanism, combined with visual feedback in the form of a 3-D Head-up Display (3D-HUD). Because of its 3-D properties, the HUD can also be used for Augmented Reality (AR) as it allows physical elements in the driver's field of view to be annotated with computer graphics. The combination of simple natural user input tailored for the constraints of the driver with a see-thru 3D-HUD allows drivers to query information while minimizing visual and manual distraction.

# ****Multi-touch steering wheel for in-car tertiary applications using infrared sensors** [8]**

This paper proposes a multi-touch steering wheel for in-car tertiary applications. Existing interfaces for in-car applications such as buttons and touch displays have several operating problems. For example, drivers have to consciously move their hands to the interfaces as the interfaces are fixed on specific positions. Therefore, we developed a steering wheel where touch positions can correspond to different operating positions. This system can recognize hand gestures at any position on the steering wheel by utilizing 120 infrared (IR) sensors embedded in it. The sensors are lined up in an array surrounding the whole wheel. An Support Vector Machine (SVM) algorithm is used to learn and recognize the different gestures through the data obtained from the sensors. The gestures recognized are flick, click, tap, stroke and twist. Additionally, we implemented a navigation application and an audio application that utilizes the torus shape of the steering wheel. We conducted an experiment to observe the possibility of our proposed system to recognize flick gestures at three positions. Results show that an average of 92% of flick could be recognized.

# ****Multimodal interaction in the car: combining speech and gestures on the steering wheel** [9]**

Implementing controls in the car becomes a major challenge: The use of simple physical buttons does not scale to the increased number of assistive, comfort, and infotainment functions. Current solutions include hierarchical menus and multi-functional control devices, which increase complexity and visual demand. Another option is speech control, which is not widely accepted, as it does not support visibility of actions, fine-grained feedback, and easy undo of actions. Our approach combines speech and gestures. By using speech for identification of functions, we exploit the visibility of objects in the car (e.g., mirror) and simple access to a wide range of functions equaling a very broad menu. Using gestures for manipulation (e.g., left/right), we provide fine-grained control with immediate feedback and easy undo of actions. In a user-centered process, we determined a set of user-defined gestures as well as common voice commands. For a prototype, we linked this to a car interior and driving simulator. In a study with 16 participants, we explored the impact of this form of multimodal interaction on the driving performance against a baseline using physical buttons. The results indicate that the use of speech and gesture is slower than using buttons but results in a similar driving performance. Users comment in a DALI questionnaire that the visual demand is lower when using speech and gestures.

# ****Gesturing on the Steering Wheel: a User-elicited taxonomy** [10]**

"Eyes on the road, hands on the wheel" is a crucial principle to be taken into account designing interactions for current in-vehicle interfaces. Gesture interaction is a promising modality that can be implemented following this principle in order to reduce driver distraction and increase safety. We present the results of a user elicitation for gestures performed on the surface of the steering wheel. We asked to 40 participants to elicit 6 gestures, for a total of 240 gestures. Based on the results of this experience, we derived a taxonomy of gestures performed on the steering wheel. The analysis of the results offers useful suggestions for the design of in-vehicle gestural interfaces based on this approach.

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