Evaluating the Potential of Head-Up Displays for a Multimodal Interaction Concept in the Automotive Environment

Markus Ablassmeier, Gregor McGlaun and Gerhard Rigoll

Institute for Human-Machine Communication
Technical University of Munich
Arcisstr. 16, 80290 Munich, Germany
phone: +49 89 289-28541

{ablassmeier | mcglaun | rigoll}@ei.tum.de

ABSTRACT

To keep the increasing amount of information in luxury vehicles easily controllable for the driver and also minimize the mental workload, sophisticated presentation and interaction techniques are essential. This contribution focuses on a user-centered analysis for an authoritative grading of head-up displays (HUDs) in the field of read-out units in cars. Two different studies delivered the evaluation data. In a field test, the potential and the usability of the HUD were analyzed. For special driving situations (city road, highway), the according display needs and requirements of the users have been identified. Moreover, the HUD was compared with redundantly competing types of in-car displays. As a result, a high acceptance of the HUD by the driver and a good performance compared to other in-car displays had been reached.

Keywords: head-up display, human-machine interaction, automotive

1. INTRODUCTION

Especially over the last years the amount of electronic devises in cars, like infotainment and comfort applications (e.g. navigation system, mobile phone, CD-player, mp3-player, etc.) has increased enormously[1]. Also advanced driver assistance systems (like adaptive cruise control or lane departure warning) entered in modern cars to help the driver in its driving process and should increase the car and traffic safety. Through the huge amount of information and functions the driver is faced with a higher complexity what strongly implicates an enlargement of in- and output modalities and efficient information presentation in cars. For this reason, this paper exemplarily focuses the potential of head-up displays for multimodal interaction concepts.

In the car domain, error-prone situations often occur regarding the human-machine interaction with different in-car applications, as the driver often has a certain mental workload[2]. This basic stress level is due to the execution of so-called *primary* (navigation, stabilization of the car, etc.) and *secondary* tasks (windshield wiping, honking, etc.), and may be increased by environmental impacts, like the conversation with a co-driver. If the driver interacts, e.g., with a communication and infotainment system in such a stress phase (*tertiary* task), inattention, distraction, and irritation occur as a consequence of the high workload resulting from a superposition of the tasks mentioned above, which will become manifest in an increased error potential and in erroneous operations of these tertiary systems. HUDs keep a high potential for an efficient and user-centered information presentation.

A further project in this field of information systems was the FERMUS-Project[3], which had been started in March 2000 in cooperation with several industry partners. The primary intention of FERMUS was to localize and evaluate various strategies for dedicated analysis of errors by using various modalities.

From: WMSCI 2005, Zinn (ed.), IIIS

2. BACKGROUND KNOWLEDGE

Head-Up Displays

A head-up display (HUD) is a means of projecting information directly into a human's visual field.
The principle of head-up displays is based on optical rules. An image is projected onto a glass window and is partially reflected. The reflected fraction is perceived by the observer as a virtual image. The distance *x* between the virtual image *a* and the glass window *c* is equivalent to the distance *x* between the image source *b* and the glass window *c* (see Figure 1).

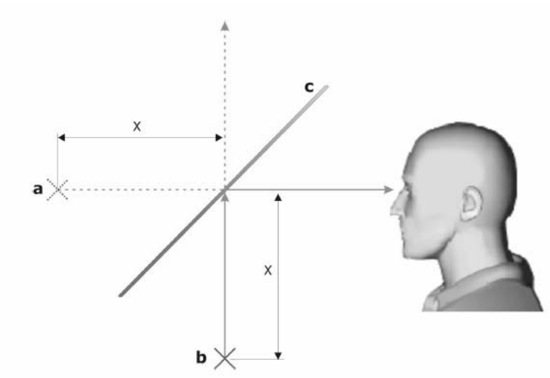

Figure 1 principle of head-up displays [4]

Head-up displays were pioneered for fighter jets in the early 70s (see Figure 2) and later for low-flying military helicopter pilots, for whom information overload was a significant issue, and for whom changing their view to look at the aircraft's instruments could prove to be a fatal distraction. [5]

Figure 2 HUD of a fighter jet

HUDs have been proposed or experimentally developed for a number of other applications, and now provide basic information for car drivers, by projecting an image onto the inner surface of the car's windscreen. This has been released as a product by a few car manufacturers. HUDs are likely to become more common in future vehicles. Important data, usually showing speedometers and navigation information (see Figure 3), can be read quickly without having to look away from the road. It appears to hover above the hood, a few meters away. The HUD should keep the driver attentive, because the driver's eyes don't have to focus from long to short perspective while the information capture.

Figure 3 HUD from Siemens VDO[6]

Eye Glance Studies

Visual behavior while driving has been studied widely since the 1960's. One aspect of drivers' visual behavior that has been the focus of widespread attention is the visual distraction caused by the use of in-car devices such as radios, phones and climate control systems. [7]
The eye glance technique measures visual behavior by recording the frequency and duration of eye glances at particular objects in the driver's visual field. When drivers perform a secondary or tertiary task while driving, they usually complete this task through a series of brief glances (1 to 2 seconds) at the object interspersed with glances at the roadway. Eye glance studies give a measure of the total "eyes off road time", and hence the visual demand or interference associated with performing the task. This method is a widely accepted and valid measure of the visual demand associated with the performance of a secondary task and is highly correlated with the number of lane excursions committed during secondary task performance.
Eye glance behavior has traditionally been measured by using a video recorder to record the driver's eye and hand movements. The time consuming process of analyzing the tapes frame-by-frame is then conducted to obtain the eye glance data. Today, sophisticated head and eye tracking devices have simplified this process and allow real-time measurement of frequency and duration of eye

glances, scan paths, eye-closures, and over-the-shoulder head turns.
The JANUS system (see Figure 4) is a head and eye gaze tracker and is capable of tracking head and eye movements under different lighting, vibration and head motion conditions[8]. It consists of a mobile component for data recording and a stationary component for post processing. The mobile component consists of a measuring helmet, a measuring rack with recording system and energy supply. Through the video transcription the task length, total glance time, glance frequency and glance duration can be measured.

Figure 4 Eye Tracking System JANUS

The JANUS system is a valid measure of the visual distraction associated with the performance of several in-vehicle tasks and is an easy to use and efficient method for testing the safety of in-vehicle systems.

Guidelines for Dialog Structures
Several guidelines are very useful for designing and evaluating interaction concepts:
The ISO 9241 part 10 [9] presents ergonomic principles which apply to the design: suitability for the task, self-descriptiveness, controllability, conformity with user expectations, error tolerance, suitability for individualization, and suitability for learning.
The ISO/DIS15005 2000 [10] describes the ergonomic principles to be applied in formulation of dialogues between the driver of a road vehicle and the information and control system when on the move: The dialog between the system and the driver must therefore take account of the workload on the driver as a whole, including the cognitive, perceptive and physical functions associated with driving, so that the dialog does not prevent the vehicle from being driven properly and safely.

This background knowledge is the basis for the following usability studies about the potential of Head-Up Displays for multimodal interaction concepts in cars.

3. EXPERIMENT AND RESULTS

Two different studies delivered the evaluation data. In a field test, the potential and the usability of the HUD were analyzed, using a test car. The test car was equipped with a driver-centered combi-display (DCD), a central information display (CID) and a HUD that projected the virtual image in a distance of 2 meters to the driver. The test track was about 60 kilometers and the average driving time was one hour. For special driving situations (city road, highway), the according display needs and requirements of the users have been identified. Moreover, the HUD was compared with redundantly competing types of in-car displays. The test persons had been equipped with the JANUS eye tracking system. They had to follow the test track and have been instructed amongst others to read the road signs and control the speed limits on the displays. For information capture on a display the glance retention period (GRP) is defined as eye fixation period plus eye movement period. 18 subjects (average age: 43.9a, 3 female) participated in the study. 85% of the test persons pointed out that they accept and desire the HUD while driving. The HUD is an important completion of the information supply, and useful for different types of drivers, independently from age, system experience, and domain-specific knowledge.

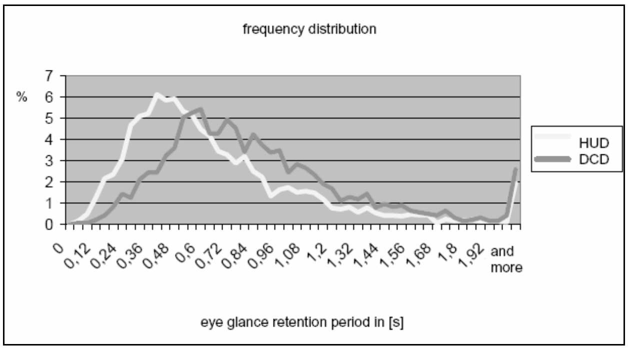

Figure 5 frequency distribution of the eye glance retention period (GRP)

In low speed situations (city road), the GRP of all users was between 15 and 20% less on average compared to the GRPs regarding the DCD and the CID. In high-speed scenarios (interstates), the averaged GRPs were even reduced up to 25%, which means that a HUD has a high potential for efficient information capturing (see Figure

5). Especially in the group of people aged between 51a and 60a, the process of information gathering from the HUD was about 200ms faster (see Figure 6).

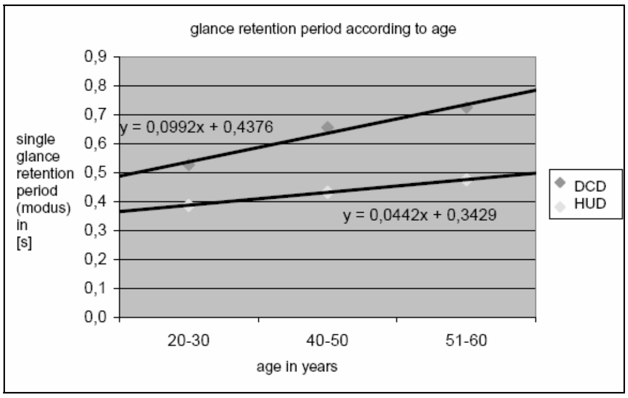

Figure 6 glance retention period according to age

Between 86% and 90% stated that information regarding speed and active cruise control should, by all means, be displayed in the HUD. Yet, the HUD cannot thoroughly replace the customary display types (CID and DCD). Only 50% could abandon the DCD, and 40% of all subjects would renounce the CID. For some applications (e.g., like displaying the navigation map or long lists), the HUD is not yet fully developed regarding visualization technology and user friendliness.

In dependence of the situational context (e.g., curves vs. straight route), we designed a field trial to evaluate special HUD layouts with regard to content and form. In this study the virtual image was projected in a distance of about 1 meter. As an important result, we have found out that, on average, the test subjects needed a total of 4,9s for mentally conceiving four symbols, in curvaceous situations even up to 5,8s. The maximum number of information symbols should not exceed three new items at a time.

On the basis of the previous test results, a comprehensive multimodal readout and operation concept has been developed and discussed.

4. CONCLUSIONS AND OUTLOOK

The main aspect of these studies has been to primarily improve the traffic safety and to accelerate the intuitive capture of information in vehicles. The results of the usability study have shown that head-up displays can deliver an improvement of efficient information presentation. Consequently the HUD has a great potential for multimodal interaction concepts in cars.
To meet the drivers' intention, further research should be focused on which and how much information should be offered in the HUD to the driver according to the context. However, phenomena like attention capture of HUDs have to be studied intensely. The drivers' attention to the traffic should not be influenced by an information overload, what could manipulate the main goal of more safety and user-friendliness in a negative way.

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