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Comparing an Innovative 3D and a Standard 2D User Interface for Automotive Infotainment Applications

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Abstract

In this work we present the results of a comparative user study of two radically different user interfaces for controlling infotainment applications in an automotive environment: a standard 2D interface and an innovative 3D interface. Based on a generic multimodal architecture, both systems can be operated by conventional key-console and touch-screen as well as by natural speech and dynamic hand and head gestures. Inspired by the advantages of classical Virtual-Reality interfaces, the idea of the new 3D design approach is to increase the overall usability when interacting with complex in-car information systems by applying pleasing display patterns. In a series of usability experiments we have evaluated both interfaces with regard to typical operation tasks in a simulated driving scenario. Thereby, we have found out that none of the two interface alternatives has clearly been preferred in general, but concerning selected design elements and the joy of use, the 3D visual front-end obtained significantly better ratings.

1 Introduction

As a matter of fact, most of the commercially available automotive infotainment systems show very poor usability which is a result of growing functional complexity and mostly restriction to purely tactile interaction. Thus, the appropriate user interfaces (UIs) require extensive learning periods and adaptation by the user to a high degree which often increases the potential of user frustration. To overcome these limitations, different strategies have been examined (BMW and PITech 2003). Most of these approaches concentrate on an optimisation of the tactile input devices and a uniformly structured representation, an ergonomic placement of the central display device and sometimes the use of speech and gestures as additional input modalities (Bengler 2000). But the visual representation is still strictly 2D. Concerning desktop applications, increased usability requirements have lead to an evolution of various interface types and interaction paradigms. Multimodal Virtual-Reality (VR) interfaces resemble the latest step in the development of human-machine interfaces. Providing multi-dimensional input possibilities and innovative audio-visual feedback strategies, these systems can be worked with both effectively and intuitively (Oviatt 2000). Moreover, the acceptance is much higher by especially increasing the joy of use.

In this work, we want to benefit from the well-known advantages of 3D UIs and try to apply them within the automotive context. Fully integrated in a multimodal framework (McGlaun 2002a), we have developed a VR interface as an alternative visual front-end to handle various in-car infotainment applications. To evaluate the performance and acceptance of the new 3D interface, we have compared it to a standard 2D interface (Althoff 2002a) in a series of usability experiments.

1.1 Related work

Several research groups have evaluated both the performance and the usability of 3D and 2D user interfaces with regard to various, mostly desktop oriented applications. Ware (Ware et. al 1996) compared user's understanding of linked node structures in a 2D and a 3D network. Taking the measured time to give the correct answer as the primary indicator, the 3D interface alternative clearly out-performed the 2D solution. Evaluating user experiences concerning the handling of non-interactive graphs, Levy (Levy et. al 1996) found a general preference for 3D graphs, particularly when used for making memorable impressions or when multiple users exchanged information with each other. With regard to a document storage application, Cockburn (Cockburn et. al 2001) tested a 2D interface and a 3D front-end that was inspired by the Microsoft Data Mountain (Robertson et. al 1998). While the group of test subjects that used the 2D interface obtained slightly faster task completion times, but no significant difference level could be identified, all users showed a strong tendency to prefer the 3D interface which results in significantly better ratings with regard to the overall usability of the system.

2 Research background

2.1 Application functionality

In our overall research work (FERMUS, 2003), we concentrate on the development of intuitive and error-robust UIs for controlling infotainment applications in an automotive environment (see figure 1). The underlying test application consists of managing multiple audio devices (MP3-player, CD and radio) and standard telecommunication tasks. Thereby, the player module provides well-known CD-player functionalities (play, pause, stop, skip, etc.) as well as more sophisticated features (indexing, programming, complex song searching, additional information retrieval, etc.). In radio mode, the user can switch between different predefined radio stations. The telephone functions are restricted to basic call handling (call, end, accept, deny, hold, etc.) of predefined address-book entries. Moreover, the volume of the audio signal, various sound quality parameters and other settings can be adjusted to the personal needs of the user in a separate control mode.

2.2 Design of the standard user interface

The standard interface (SI) has already been used in various research projects and usability studies (e.g. McGlaun 2002b). Although it has continuously been improved, its front-end is still reduced to a few fundamental elements only. In general, the visual representation is organized in four separated horizontal areas (shown on the left in figure 1). The top line is composed of four buttons representing the individual modes of the application (*MP3*, *radio*, *telephone*, and *control*). Directly beneath this button line, as the central design element, the interface provides a list containing individual items that can vertically be scrolled through by the two buttons on the right. The area in the lower part contains context specific buttons varying from mode to mode. In addition, the last line of the interface contains a feedback line continuously informing the user of the system status, e.g. the current volume, the name of an incoming call connection or additional information for the audio tracks.

2.3 Multimodal system environment

The system can be operated by a touch-screen and a special key-console that is shown on the right side of figure 1. The buttons are organized in direct analogy to the layout of the buttons on the touch-screen. In addition, two push/turn buttons are provided: one for adjusting the volume and one for browsing in the list. The recognition of speech, hand and head gestures provides an important step towards more natural man-machine interaction. Both command and natural spontaneous speech utterances can be used. Gestures often support speech. For selected functionalities and in noisy environments, they provide a valuable alternative to purely tactile and speech-based input. In general, the individual input devices are designed in a way to support the full spectrum of functionalities, i.e. they are not restricted to device-specific interaction forms a priori.

For exchanging information between the individual modules of the system we have developed a special communication architecture based on an extended context-free grammar formalism. As the grammar completely describes the interaction vocabulary of the application, it facilitates the representation of both domain- and device independent multimodal information contents. Thus, natural speech utterances, hand gestures, and specific tactile interactions can be described via the same formalism. The terminal symbols of the grammar represent the smallest significant semantic units of potential user interactions. In a client-server approach, multimodal information units are exchanged in the form of indexed string messages over TCP/IP sockets (McGlaun, 2002a).

Figure 1 (from left to right): Standard interface, working environment and layout of the key-console

3 Virtual-Reality user interface

3.1 Interface design

The new 3D Virtual-Reality interface (VRI) is supposed to provide an alternative visual front-end to the functionality of the SI. Fully embedded in the existing multimodal system architecture, the VRI can be operated by the same input modalities. Although the innovative aspects mainly focus on an improvement of the visual representation, some new features are introduced, too.

The organisation of VRI consists of four functional groups that correspond to the four modes of the underlying application (MP3, radio, telephone, and, as an extension to the original functionality, a prototypical browser for WAP content). Each mode is denoted by a special color. Independent of the current mode, a single view is always composed of four structural elements: an *icon bar*, two *wheel buttons*, a *list display* and a separate *status bar,* which are now explained.

Figure 2 shows from left to right the MP3-mode, the telephone mode and, as a new feature, the WAP mode. At the lower end of the visual display area, the interface provides an icon bar consisting of four small colored buttons, representing the individual modes and devices, respectively. Selecting a specific mode is done by simply touching the appropriate icon on the display.

The interface provides two wheel buttons on left and on the right side of the list area. Whereas the left wheel can be used to adjust the current volume, the wheel on the right serves as a scrolling device for scanning through the individual entries of the list. Each wheel comes along with two special arrow buttons of variable length that give an impression of how many entries are contained in the list if scanned in the indicated direction. Located at the side of the wheel buttons, the VRI additionally provides a standard 2D scroll-bar covering the same functionality as the buttons.

In the center of the display area, the interface provides a list showing the individual entries (songs, radio stations and telephone numbers). Each visible entry can directly be selected by a simple touch. The list is organized in form of a cylinder with the entries shown on its curved surface. Scrolling in the list is visualized by virtually rotating this cylinder. To improve the impression of a rotating surface, the cylinder is slightly turned while scrolling. This mechanism should facilitate a natural anticipation since more entries are shown in the intended direction of the search. Releasing the scroll wheel results in a flip-back of the list. Additionally, the list area provides a special feature. By virtually pulling on the upper border of the list, the cylinder can be turned over, offering a context specific option menu. Using this display metaphor facilitates a kind of implicit submenu without the need to change the basic modes. The additional area can be used for example to provide a number pad in the telephone mode or detailed traffic information in the radio mode.

The status bar in the upper area of the interface serves for informing the user of the currently active application and, additionally, provides the basic interaction functionality in a very compact form. In MP3 and radio mode, this holds for skipping, in the case of the telephone mode it stands for accepting and denying a call. The status bar facilitates a mode spanning operation of the other devices without the need to really change the modes. This feature is extremely helpful since it provides an elegant possibility to adapt the interface to personal needs, e.g. the MP3 device can still be operated while the user is searching a specific name in the list of telephone book entries.

Figure 2 (from left to right): Design of the MP3-mode, the telephone mode and the WAP mode of the VRI

3.2 Extended application functionality

Among various new features, we implemented a prototypical WAP-browser. As shown on the right side of figure 2, the user can always interact with a selection of WAP sides that represent a kind of history or bookmark functionality of standard HTML browsers. Similar to the Microsoft Data Mountain, the individual WAP sides can be rotated on predefined paths. This can either be done by directly selecting a WAP side or by scrolling with the right wheel button. Like in other common browsers, the interface provides additional buttons for certain frequently used functions like *link back*, *link forward* and *home* at the lower end of the display.

3.3 Presentation technology

For the display design of our VR interface we make use of the VRML standard, which is a declarative language for describing interactive virtual 3D scenarios (VRML97). By integrating special VRML plugins, generic 3D content can be displayed in standard web browsers. For communicating with the other modules in our multimodal setup, we rely on an extended heterogeneous architecture for navigating and manipulating objects in arbitrary VRML worlds (Althoff 2002b). Although technically realizable, we explicitly do not include an avatar in the virtual scene. We solely apply a first-person-view which, on the principle, strongly corresponds to the planar view of the 2D standard interface and other common automotive interfaces.

4 User study

The goal of the user study is to evaluate the performance and the general acceptance of the 3D interface alternative compared to the standard 2D solution, especially with regard to the multimodal interaction behaviour and preferences, task completion time, display retention periods, subjective user experiences and an isolated rating of the introduced new features.

4.1 Test environment

The user study is carried out at the usability laboratory of our institute that has specially been adapted to evaluate multimodal user interfaces in automotive environments. To simulate realistic conditions in non-field studies, the lab provides a simple driving simulator, consisting of a specially prepared BMW limousine with force-feedback steering wheel, gas and break pedals, as well as a gear stick. The test subjects have to use these devices to control a 3D driving task, which is projected on a white wall in front of the car. Thus, they can experience the driving scenario from a natural "in-car" perspective and better anticipate the roadway. The individual parameters of the simulation can fully be controlled, e.g. the degree of the curves, day or night sight conditions, speed regulations, obstacles or passing cars. For interacting with the interface, the test car contains a 10" touch-screen, a special key console and additional buttons on the steering wheel. Furthermore, the car is equipped with microphones and cameras to supervise the test subjects. The audio and video signals from inside the car are transferred to a separated control room that serves for recording and analyzing the user interactions with the test interface and the driving performance.

4.2 Test methodology

The functionality of the interface is partly realized according to the so-called Wizard-of-Oz test paradigm (Nielsen 1993). In contrast to the tactile user interactions by the touch-screen and the key console that are directly transcribed by the system, the recognition of the semantic higher-level input modalities (speech, hand and head gestures) is simulated by a human person supervising the test subjects via audio and video signals in the test room. The so-called 'wizard' interprets the users intention and generates the appropriate system commands, which are sent back to the interface in the car to trigger the intended functionality. Thereby, the wizard is instructed to be extremely cooperative. In the case of ambiguous inputs, the interaction is perfectly interpreted in the current system context. By following this approach, we can guarantee that no additional error potential is introduced by randomly distributed malfunctions of real recognition modules.

4.3 Test preparation

Before starting the real test run, the test subjects are familiarized with the functionality of both the driving task and the two interface alternatives in an extensive, interactive training period together with the wizard, mainly by using the tactile input devices. At the same time, the use of natural speech and gestures as well as potential combinations of the individual modalities are explained. Although, in general, the test subjects are free to use their own speech and gesture vocabulary, certain possibilities are explained that have already proven to be meaningful in related experiments (Zobl 2001). For example, making a wiping move with the right hand stands for skipping in the playlist or shaking the head can be used to deny an incoming telephone call. The subjects are motivated to take the driving task seriously by a performance-dependent reward.

4.4 Test plan

In the real test session, the two interfaces are presented in random order to avoid anticipation and learning effects. On the background of a relative simple driving task, the test subjects have to accomplish 26 different operation tasks that are almost uniformly distributed among the individual command clusters. Depending on the individual performance, each stage lasts for about 10 to 15 minutes and contains similar operation clusters. To make sure that the participants do not devote most of their visual attention to the interface, they are distracted by various events (appearing obstacles, speed regulations, changing visual boundary conditions, etc.). Additional questionnaires after each part help to evaluate the subjective user experiences.

5 Results

A total of 17 persons participated in the test trials with 12 male and five female subjects. Besides 12 students of different faculties, five employees were among the testers. The average age was 27 years. For all subjects, this was the first usability test concerning the operation of in-car comfort devices. Most of the subjects were technically highly skilled and stated to drive cars regularly.

5.1 Task completion time

Among the big variety of operation tasks, we specially evaluated the task completion time with respect to two volume control tasks (T1 and T5), one skip task (T2) and two list selection tasks (T3 and T4). The results are shown in seconds on the left in figure 3. Concerning the volume control tasks, in general, no significant difference between the completion times of the two interfaces could be observed. Although for T1 the operation times are a bit longer ($p<0.1$), for T5 even a two-sided test did not show any significant differences. This result contradicts the expectations that the VRI is easier and faster to operate.

Concerning the selection task, we find longer operation times for the VRI ($p<0.05$) which confirms the expectations and also the subjective user experiences that, due to the turning cylinder, the operation tasks are slightly longer. Concerning basic functionalities like the skip task (T2), no significant difference in the task completion time of the two interfaces could be observed ($p<0.01$). Moreover, a single-sided test even results in significant longer operation times for the SI ($p<0.1$). This again corresponds with the expectations, since the VRI has been designed in a way that it can be handled at least as easy and intuitive as the standard interface.

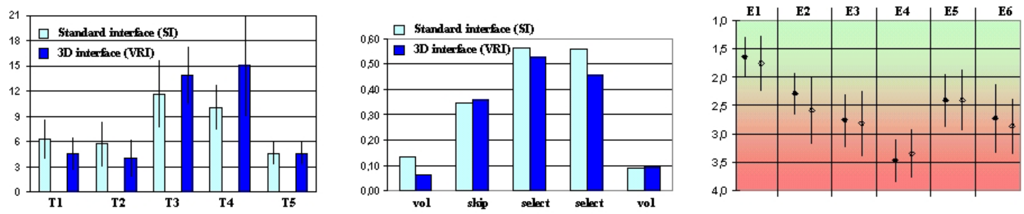
5.2 Standardized retention periods

As an interesting result we found out that the standardized display retention period (SDRP), which is the fraction of the total task completion time the user looks at the display in percent, is almost identical for comparable tasks for both interface types (see middle diagram of figure 3). The SDRP value can be used as a good approximation for the workload that the interface imposes on the user. High SDRPs can be interpreted as a high visual display attention and, therefore, as an indicator for the fact that operating the interface obviously distracts from the primary task of driving the car and thus influences the driving performance in a negative way. This assumption could explicitly be confirmed in the WAP mode. Since this mode demands special attention, users correcting the current driving path as well as virtual deviation events could be observed more frequently. The distraction from the driving task, that is induced by the two interfaces, is nearly the same, concerning the VRI in most cases even a bit less. Thus, in general, the VRI has met the expectations of not inducing additional error potential compared to the standard interface.

Figure 3 (from left to right): Operation times[sec] of selected tasks; standardized display retention periods for various command clusters; evaluation of selected new features of the VRI with regard to the two adjective pairs (intuitive-ambiguous) and (meaningful-unnecessary), please refer to the text for feature explanations

5.3 Modality preferences

Speech as the primary input modality has been preferred by most of the participants. It was used even more intensively when operating with the VRI (in 38.2% of all interactions) than with the SI (30.4%) concerning all test persons and scenarios. In both interfaces, touch-screen interaction represented the second best modality choice (applied in 24.3% of the operations for the VRI and in 28.0% for SI, respectively). The key-console has been used more frequently in the reference



interface (23.5% compared to 17.5% for the VRI). Hand gestures were used in 15.5% of all SI interactions and only in 11.6% of the VRI events, mainly for the skipping functionality and for adjusting the volume parameters. Head gestures rarely occurred. When applied, they were exclusively used for yes/no decisions like accepting or denying an incoming phone call.

Synergistic multimodal interaction (Nigay et. al 1993) behavior in the form of simultaneously communicating complementary and/or redundant information units via different modalities occurred in selective cases only. Nevertheless, the parallel availability and the multiple modes for achieving the same functions obtained top ratings. The test users highly appreciated having the possibility to freely choose among multiple input devices and not to be forced to use a certain predefined interaction style. Concerning the automotive scenario, this is the biggest benefit of a multimodal system architecture. In general, the importance of purely tactile interaction with touch-screen and key-console massively decreases within a multimodal system environment.

5.4 Acceptance and subjective user experience

A definite preference of the test users for one of the two interfaces could not be observed, since nine out of 17 participants preferred the VRI and seven the SI, respectively. One person could not clearly state any liking. The usability of the two interface types has been evaluated according to a four point semantic differential method with regard to the following eight adjective pairs: motivating vs. frustrating (A1), intuitive vs. ambiguous (A2), effective vs. ineffective (A3), reliable vs. insecure (A4), easy vs. complicated (A5), clearly vs. confusing (A6), attractive vs. boring (A7) and, finally, simple vs. overloaded (A8). No significant differences could be observed with respect to five out of these eight adjectives (A1, A2, A3, A5 and A6). Concerning the other three pairs, the VRI was evaluated more reliable (A4) and more attractive (A6) on a basis of $p<0.01$, but also more complicated to be operated and visually overloaded compared to the SI ($p<0.01$). The individual results (average values and standard deviation) are summarized in table 1. Thereby, a value close to 1 stands for a majority rating for the first adjective (e.g. A1: motivating), whereas a value close to 4 represents a definite voting for the second adjective (e.g. A1: frustrating).

		SI	VRI				SI	VRI	
A1	motivating	**1,47 (0,49)**	1,65 (0,70)	frustrating	**A5**	easy	1,59 (0,61)	**1,41 (0,63)**	complicated
A2	effective	**1,47 (0,50)**	1,59 (0,61)	ineffective	**A6**	clearly	**1,53 (0,84)**	1,76 (0,70)	confusing
A3	intuitive	1,53 (0,84)	**1,47 (0,62)**	ambiguous	**A7**	attractive	2,35 (0,80)	**1,71 (0,61)**	boring
A4	reliable	1,94 (0,53)	**1,53 (0,61)**	insecure	**A8**	simple	**1,47 (0,50)**	2,00 (0,95)	overloaded

Table 1: Average rating and standard deviation on the basis of a four point differential method for the two interfaces (VRI and SI) with regard to eight different adjective pairs (see text for details)

5.5 Evaluation of new features

After testing both interface alternatives, the test subjects had to evaluate the usability of the new 3D design elements. The right diagram in figure 3 shows the results with respect to the same four point semantic differential method and the adjective pairs intuitive(1) vs. ambiguous(4) on the left of each column and meaningful(1) vs. unnecessary(4) on the right, respectively. Thereby, the columns denote the following design elements: the two wheel-buttons (E1), the list display on the curved surface of a cylinder (E2), turning the cylinder while scrolling (E3), the delayed automatic flip-back after selecting a list entry (E4), the possibility of turning over the list display for the option menu (E5) and the arrangement of the WAP sides as well as the WAP content (E6).

Concerning the introduced 3D design elements, the wheel buttons have been rated very positively. But the benefits of applying the 3D design pattern of a scroll-wheel in an automotive environment have been seriously questioned, since the functionality in the test interface was extremely sensitive to the point of touching the screen. The reactive area on the touch-screen device should be enlarged along the vertical axis to accept touches slightly above and beneath the button, too.

The list display on the curved surface has been neglected by most of the subjects. This applies even more for the turning surface, which was stated to distract from the driving task massively. Especially in an automotive environment, where the user should normally only devote a preferably small amount of attention to the interface, it is a major problem if the focus of the current entry in the list moves while scrolling. Concerning the turnover mechanism of the list display, most of the test users did not comprehend the functionality immediately. After a detailed explanation, the additional feature was rated as being easy to operate and highly meaningful in everyday use. Altogether, this lead to an average neutral estimation of the turn functionality.

The special feature to operate two different modes at the same time by the separate status bar has rarely been used, mainly due to the fact, that the users could not freely play around with the interface but had to fulfill predefined tasks and, thus, were quite pressed for time. Therefore, the status bar obtained an average rating (2.1). Both the additional scrollbars and the scroll arrows near to the wheel buttons are an unnecessary optical gimmick in the eyes of most test subjects, tending to result in negative evaluation (2.8).

6 Conclusions and future work

In this work, we have presented an innovative 3D user interface for controlling various infotainment applications in an automotive environment. We have conducted a series of usability studies to evaluate the acceptance and the performance of the 3D UI compared to an established standard 2D solution. In a complex experimental Wizard-of-Oz setup, the test subjects had to operate various in-car audio and telecommunication devices while simultaneously performing in a realistic driving task. To summarize the results, selective 3D design elements could significantly increase the overall usability and the joy of use, but others should definitely not be used in automotive environments. In general, the users demanded for a clear and simple structured display, which does not distract them while driving. Confirming related experiments, the importance of purely tactile interaction decreases within a multimodal setup. As an interesting result we obtained that none of the two interface alternatives has clearly been preferred by the test subjects.

For the nearest future we further plan to improve our interfaces, e.g. by directly integrating context specific error handling mechanisms and providing more feedback to the user. Moreover, we want to run detailed statistical tests on the existing audio-visual data material to collect more information on the multimodal interaction patterns, the length of speech and gesture interactions and the inter-modal time dependencies that occur in automotive environments. Selected parts of this work have already been presented in (Althoff 2003). Finally, we are currently about to discuss both our design approach and the results of the evaluation in the context of similar work in a purely desktop oriented application scenario.

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