Designing Context-aware In-car Information Systems

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ABSTRACT

In-car information systems are becoming increasingly complex. A multiplicity of functions in the area of navigation, information, communication, entertainment, comfort and security is available to the driver. The human-computer interaction is situated in a highly dynamic environment with specific demands to the drivers' cognition. The dynamically changing context can influence the quality of interaction, e.g. with regard to the usability. Systems with user interfaces that adapt to context information are potentially capable to offer a suitable quality of interaction by adressing the drivers needs and goals in varying driving situations. However, adaptions of the user interface also hold threats to the quality of interaction. In a qualitative user study this work explores the users' reaction towards a context-adaptive user interface of an in-car navigation systems regarding information display and interaction mechanism. The basic challenge discussed in this paper is the question whether and how context should be an influencing factor for the user interface and user interaction.

Categories and Subject Descriptors

H.1.2 [**User/Machine Systems**]: Human factors; H.5.2 [**User Interfaces**]: Evaluation/methodology, Input devices and strategies, Prototyping, User-centered design.

Keywords

Context adaptation, navigation systems, automotive, prototyping, user study, simplicity.

1. INTRODUCTION

Our working and everyday life is infused with interactive systems. Hence we are faced with user interfaces of these systems permanently and as actors in a specific context we try to reach our goals and complete our tasks by interacting with these systems. Context in this case means the ambient world surrounding the interacting user ("outer context"). In addition context also denotes the inner world of an user, e.g. her/his experience, goals, needs, motivations, feelings, cognitive structures and processes ("inner context"). Context can change during time and will influence the situation an user acts in. In many situations the interaction of the user with a system is affected by the context. Thus, context is an influencing factor on the quality of interaction between the user and the design of a system. This implicates that context factors may also influence the usability of the user interface in certain situations.

For example, it could be difficult to read the information on a display in a covertible, when the roof of the car is opened and the sun is shining (information display). Due to the high sound level in an opened convertible, the voice control to interact with the system could be impeded (interaction mechanism). A system that automatically adapts its user interface (information display and interaction mechanism) to the corresponding context would be desirable (context adaptation). A situational adaptation of the user interface to the current context would help users to achieve their goals with the system effectively and satisfactorily. Especially in situations in which the context changes frequently, abruptly or significantly a context adaptive interface could offer additional benefit in comparison to non-adaptive systems.

This paper discusses the question whether and how context should be an influencing factor for the user interface and user interaction. The approach to the question is threefold: Firstly it is necessary to explore if users can understand the extent of the adaptation to theoretically use the newly-created possibilities (affordance). Then it is nesessary to determine if users react positively towards the newly-created possibilities and if they accept them (acceptance). Then it becomes possible to investigate if the newly-created possibilites allow the user to actually reach his/her goals and if it is possible to do this in a satisfactorily way (effectiveness/satisfaction). We explored this question in a case study with context-aware navigation system for in-car use.

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2. BACKGROUND

2.1 RELATED WORK

Much research has been done in the field of mobile context-aware applications and devices whereas most of them solely or predominantly use the context parameter "location" since it is quite easy to acquire using the Global Positioning System (GPS). There are many navigation systems for mobile or in-car devices existing that make use of GPS data, display maps and routing information (e.g. [23, 7, 25, 24]). Further on some solutions exist for using a mobile navigation application inside a building where GPS is not available. Such systems are often based on IR tracking [21], Bluetooth, WLAN, ultrasonic tracking [22] or other tracking technologies. Some of these mobile navigation systems also take other context parameters into account, e.g. the position of nearby persons or objects, Points of Interests (POIs) or computational resources [19, 20]. Because context means more than just location in the field of mobile applications few approaches exist for taking further context parameters into account e.g. [18]. In the field of mobile outdoor navigation systems a couple of approaches exist that make use of location based services [5] [6]. However, user interfaces should react regarding to the context. For example the input modality could change by using graphical user interfaces to an auditory interface when a user starts walking around [14]. Another example is based on the idea of changing the font size on the display while the user is walking [17]. An approach where the information display of an in-car navigation system is being adapted contingent upon the context is shown in [34] and [28]. Here the aim is to reduce the drivers' cognitive load through the generalisation of the information display. An approach using artificial intelligence to realize context-adaptive POIs in an in-car navigation systems can be found in [33]. Further on user interfaces can provide different options for different users according to their rights, know-how [15], preferences or habits [16]. They should only offer interaction possibilities that are valid to the current context and hide others [18].

2.2 IN-CAR INFORMATION SYSTEM

The interaction with in-car information systems has become an important factor of the overall driving experience. Some car manufacturers realize the access to the multiplicity of available functions of in-car information systems with integrated multi-functional devices (e.g. Mercedes COMAND [8], BMW iDrive [9], Audi MMI [10]). But "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". [35] Thus, the multipiicity of functions can have a negative impact on the usability of such systems and therefore the driving experience can be embittered by a frustrating operational concept. It seems useful to combine the multiplicity of functionalities with usable operational concepts that consider all factors of a good user experience: the design of the user interface, the interaction mechanism and the usability. A promising approach to face the heterogeneous flood of functionality is a context-aware system that is "subtracting the obvious, and adding the meaningful" (concept of simplicity) [29] with respect to the driving situation. Applying the concept of simplicity can thus mean to remove, add or replace a component of the user interface, e.g. interaction devices.

2.3 TEXT INPUT DEVICES

Research in the field of interaction techniques and input devices for entering text into (mobile) devices is often focused on the input speed. The most famous way of entering text into a computer is using a keyboard. Most personal computer users are equipped with a QWERTY/QWERTZ keyboard. In particular situations, e.g. where both hands are occupied, alternative input devices and modalities might be more useful. Many devices that are based on new input techniques like multipress or T9 (both often used for the input of text messages with a mobile phone) have to be learned by the user and require high attention. In addition to that, entering the text is (usually) slower than with standard keyboards [11]. Another approach is the use of so called non-keyboards [12]. Since touchscreens are available the use of soft keyboards is widespread. Users may point with their fingers or with a pen on a virtual keyboard displayed on the screen. When providing visual or auditory feedback this technique is also very reliable and up to 40 wpm (words per minute) are reachable using soft keyboards [12]. Speech input is a very natural and intuitive way of interacting with a device. Speech recognition is often error-prone regarding the input of text. The advantage is that it can be very fast (46 wpm [12]).

In this paper we analysed different devices for text input that could be particularly useful in in-car situations: a touchscreen operated with one or more fingers, a multifunction knob that is rotate- and pushable and a wheel slider that is operated with one finger (see Figure 1).

Figure 1: The three input devices we used in our user tests: multifunction knob, touchscreen and wheel slider

3. PROCEEDING

To explore the question whether and how context should be an influencing factor for the user interface and user interaction we analysed the correlation of user goals, context factors, system functions, user interface (information display and interaction mechanism) and usability. In this paper we present an approach of a context-aware navigation system for in-car use. We developed the prototype of a navigation system that allows to change a) the input devices (interaction mechanism) and b) the way information is being displayed (information display) dependent on specific context factors. We used the context parameters location, speed, driving direction and the track conditions (onroad or offroad). In a user study a) the process of entering text into the navigation system while standing respectively driving and b) the users perception of displayed routing information to find a given destination in different terrrain conditions (onroad-offroad) have been explored.

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3.1 USER-CENTERED DESIGN

To understand the domain of in-car navigation systems the authors conducted a contextual inquiry [30] with three users. We observed and interviewed the users interacting with their navigation system in their cars and created use case scenarios [26] and personas [27] to analyze the requirements towards the system from a users perspective. The development of paper-based prototypes (mock-ups) led to a solution for the adaptive user interface of the navigation system. The rapid prototyping and implementation of the system were embedded in an user-centered agile development process [31], [32].

3.2 FRAMEWORK

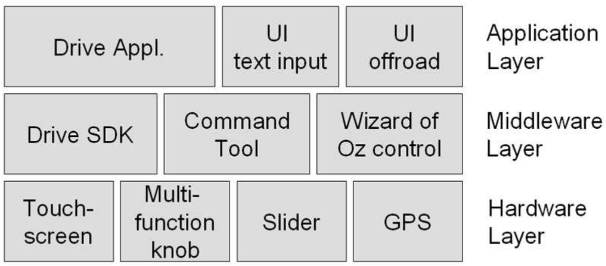

Figure 2: The framework of the testing system

This section describes the framework of the test application that was used to process the user tests and evaluate the context adaptation of the user interface. Figure 2 shows the model of the framework. The test application was built using Microsoft's .Net Framework.

3.2.1 HARDWARE LAYER

The developed application was installed on a Car-PC, equipped with two GPS mice for position tracking and input/output devices.

Touchscreen: We used a 7" VGA TFT touchscreen display with the aspect ratio 16:9 and a physical resolution of 800 x 480 (physical dimension of 154 x 93 mm). It is equipped with an autodimmer for adjusting the brightness to the illumination of the surrounding and with audio speakers. The touchscreen display was installed on the car dashboard. It acts like a simple pointing device and for the output of visual and auditory information. Figure 1 b) shows the touchscreen.

Multifunction knob: The multifunction knob is a space navigator from 3Dconnexion [3]. It supports six degrees of freedom but in our scenario it was used as a simple rotate-push-device similar to the BMW iDrive. Rotating the knob to the left or right enables the driver to select a character in order to enter her/his destination. Pushing the knob down finally selects the highlighted character. Figure 1 a) shows the device. We captured the given events using DirectX.

Slider: Wheel sliders have become very popular. We implemented the Quantum QWheel [2] Slider to allow the driver to scroll the characters with this simple and intuitive device. The QWheel evaluation board also consists of 7 touch buttons that were used to select the highlighted character in order to enter the destination. Figure 1 c) shows the QWheel evaluation board. The board offers the possibility to connect it to the Car PC via USB. The slider and button states can be queried using a USB library.

GPS: We used two GPS mice in our system setup. One mouse provides the navigation system Sygic Drive with GPS data. The other one supplies GPS data to the Command Tool in order to acquire the current context and to display the car position on the offroad user interface.

3.2.2 MIDDLEWARE LAYER

Drive Application and SDK: Sygic Drive is a GPS navigation software for a wide range of mobile devices like PDAs, smartphones or Car-PCs [4]. It offers 3D rendering for a perspective view of maps including streets, landscapes, places and points of interest. Sygic Drive is available for Windows and Linux systems and contains a SDK for third party implementations. For our test scenario we used Sygic Drive for Windows XP and the SDK to configure and control the navigation software. Further on it is possible to configure Drive via text based config files that allow the configuration of the user interface, the menu items and many other things. The SDK that is available with Sygic Drive offers possibilities to control the navigation software during runtime. It is a command based communication interface written in C++. Some of the main functions that have been used for our test scenario are:

- **AddPOI**: Adds an arbitrary point of interest to the itinerary (e.g. a new destination point with description)
- **BringApplicationToForeground / BringApplicationToBackground**: Enables the controlling of the Sygic Drive window. This allows a developer to use his own application to e.g. enter the destination address and than switch back to the navigation software in order to calculate and display the route.
- **Transformations**: These functions offer a transformation between addresses (text descriptions), points of interests and geo-coordinates.
- **NavigateToAddress**: Calculates the route between the current GPS position and an arbitrary address (text description).
- **StartNavigation**: Starts the navigation that was previously calculated.
- **SendGPSData**: Sends GPS data to Sygic Drive. This function can be used to emulate GPS data in a laboratory test field (indoors).

Wizard of Oz control: Sygic Drive is not able to inform the components of our application about the event that the driver has left a registered track. For this reason we implemented a Wizard of Oz [13] control mechanism that allows the test supervisor to manually switch from the Sygic Drive view to the offroad user interface in the very moment the driver leaves the track. The switching is triggered via a simple key press on the Car PC keyboard.

Command Tool: The command tool is our basic middleware component. It starts Sygic Drive, sends commands to it and manages the windows and user interfaces respectively. It communicates with the hardware components and thus acquires the context of the car in order to react to context changes.

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3.2.3 APPLICATION LAYER

User interface for text input: We developed our own user interface for entering the destination of a travel. This enabled us to test different user interface renderings, apply context adaptive user interfaces and use different input devices for entering text. The user interfaces for text input were developed using C# and they make use of a simple database that contains city and street names. This database was created in order to ease the text input by disabling all characters that are not allowed in the current context (for example if the user already entered "PADERB" the only allowed following character is "O" because the only possible city in this context is "PADERBORN"). We developed two kinds of character alignment: A QWERTZ alignment and a ABC alignment. The QWERTZ alignment is from our point of view the best solution when text is entered via the touchscreen because users are familiar with this alignment from PC keyboards. The ABC alignment was used in association with other input devices that offer a sequential scrolling of the selected character. Figure 3 shows the two different user interfaces that have been developed and used in the test scenario.

User interface for offroad navigation: To support a car driver that has left a registered track we designed and implemented a user interface with a map overview of the corresponding area that displays the current vehicle position based on GPS data. The user interface also displays information about the direction to the destination in form of a compass including an arrow. Further on the user interface reports the distance to the destination in kilometers. Figure 4 shows a screenshot from the offroad user interface.

4. USER STUDIES

To explore the affordance, acceptance and effectiveness / satisfaction of a system that changes its user interface two user tests have been conducted. One user test focused on a context-adatptive interaction mechanism, the other one on a context-adaptive information display. The user tests are being described in the following. The descriptions are split up in a description of the experiment setup, the experiment lead-through and finally the results. Prior to the two (main) user tests we arranged one (preliminary) user test to decide about which text input devices to use in the subsequent test about interaction mechanism. Due to the fact that our system is still an early prototype we did a user study with just a small number of participants.

4.1 TEXT INPUT DEVICES

In a preliminary study we analyzed different devices for entering text into the navigation system using the crated user interfaces (see Figure 3). Therefore we asked eight test persons to enter a given destination into our application using three different input devices. The times the test persons needed to enter the address were measured by the system and we further did short interviews in which we analyzed the user experiences and positions. The background for this study was to find tendencies which input devices are accepted by users and how applicable they are. Due to the small sample of participants we did not calculate a statistical significance.

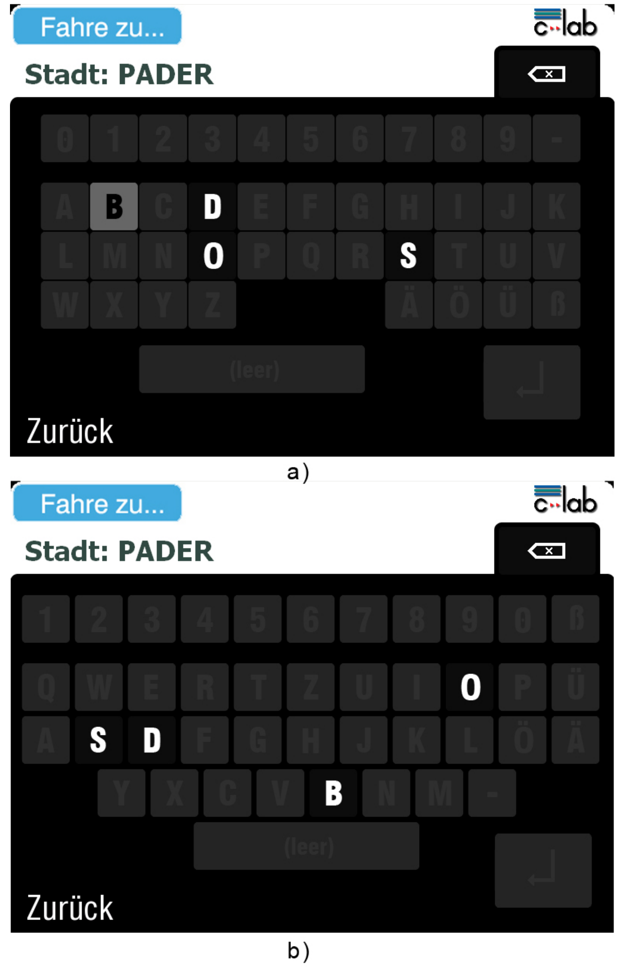

Figure 3: User interfaces for text input: a) ABC alignment, b) QWERTZ alignment

4.1.1 EXPERIMENT SETUP

We used the three different input devices described in section 2.3: A touchscreen, a multifunction knob and a wheel slider. The touchscreen was used with a QWERTZ alignment of the keys while the other devices offered key scrolling with an ABC alignment of the keys. The selection of a character was done via pushing the multifunction knob and touching a key on the slider wheel respectively. In all three cases characters have been disabled that are not allowed to enter in the current situation. The system therefore analyzes all entered characters and decides which characters may follow and which not based on our city/street database.

4.1.2 EXPERIMENT LEAD-THROUGH

The experiment always started with the touchscreen and in every case the users had the possibility to try out the input device by entering an arbitrary address of their choice. Entering an address is split up in three parts that all have to be finished by selecting the enter key: Entering the city, entering the street and entering the house number. The destination address in this experiment always was the ad-

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Figure 4: The offroad user interface

InputDevice	Avarage T	Slowest T	Fastest T
Touchscreen	29.63 s	56.37 s	26.20 s
Multifunction knob	50.38 s	56.57 s	40.14 s
Wheel slider	51.57 s	56.52 s	44.02 s

Table 1: Time measurement results for entering text

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4.1.3 RESULTS

All test persons were experienced users of computers and most of them were also experienced users of mobile devices (PDAs, smartphones, MP3 player...) and navigation systems. After the tests we held short interviews and found out that 37,5% preferred the touchscreen as input device for text input. The other 62,5% preferred the wheel slider. The main reason for this mentioned by the test persons was that the wheel slider is very intuitive and very pleasant to use. Table 1 presents the average times for entering text into the navigation system using the touchscreen, the multifunction knob and the wheel slider.

The measured times show the tendency, that the touchscreen might be the fastest among the devices for text input. The slowest times for each device are nearly identically at 56 seconds. This could lead to the idea that every user has his own preference and capability to use an input device. Table 2 shows the results of the question how the test person would evaluate each of the three devices. 1 means bad, 2 means difficult, 3 means OK, 4 means good and 5 means very good. The subjective rating shows that people seem to like the touchscreen. We did not explore if there is a correllation between input speed and staisfaction with a device.

At last the test persons were asked to optionally write down some comments and hints. Here we found out that the multifunction knob needs some fine adjustment for pushing it down. It often took a user more than one try to successfully enter a selected character. This led in two cases to a high frustration of the test persons. The auditory feedback of the system was commended by most users because it helps to keep the main attention of a user on driving the car. Some test persons mentioned that the button alignment of the wheel slider would be better if the enter button would be in the middle of the slider wheel. One person that is familiar with wheel sliders mentioned that these are difficult to use while moving (e.g. on bumpy tracks). The preliminary user test helped to evaluate which input technologies to use in the subsequent user test, to fix bugs an perform some fine tuning (technical prototyping).

Device:	Touchscr.	Multif. knob	Wheel slider
Evaluation:	4.2	3.6	3.8

Table 2: Evaluation of the three input devices

Figure 5: User studies: a) Entering destination while standing, b) Driving offorad using the offroad user interface, c) The offroad track

4.2 CONTEXT-ADAPTIVE INTERACTION MECHANISM

After looking at different devices for text input in the preliminary user test, we conducted the first main user test to find out how people react to an in-car information system that changes its interaction mechanism contingent upon the context. The aim of this second user test was to get qualitative feedback from users what they think of a navigation system that can be operated with different text input devices in different contexts. Thus this second test was entirely based upon qualitative data. Data was being obtained by observing users while interacting and listening to their expressed think alouds. After the user test the impressions were validated with the users in an interview.

4.2.1 EXPERIMENT SETUP

In this user test different persons participated compared to the preliminary user test. All of the six test persons had used some navigation system before. Due to a self-assessment, the test persons are intermediate to expert users of navigation

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systems. But experience with navigation systems varied: 4 subjects declared to have used navigation systems less than 10 times in their life, one 20 to 30 times and one test person stated to have used navigation systems more than 100 times. We again tested our application with different text input devices but this time we extended our navigation application by context-adaptivity and the user was being performed in a car. The application now offered two different text input devices (with corresponding interaction mechanisms) while the car is standing whereas the system can be operated only by a single text input device while driving. The decision whether the car was standing or driving was determined via a GPS sensor. Based on the result from the first user test, we offered the (apparently popular) touchscreen and the multifunction knob.

4.2.2 EXPERIMENT LEAD-THROUGH

The user test was split into three stages:

- In the first stage (car is standing), users had to enter a given destination into our application with the touchscreen. Then they had to enter another given destination (with the same amount of characters) with the multifunction knob.
- In the second stage (car is standing), again users had to enter a given destination. But this time they were allowed to choose between the two devices freely.
- In the third stage (car is driving), again users had to enter a given destination. Text input via the touchscreen while driving was disabled because of legal restrictions. No message (neither visual, nor auditory) was offered to the user to signal, that the touchscreen was disabled. Users had to use the multifunction knob while driving.

The first and second stage were really just preparatory. Users should get to know the system and build a personal preference to one of the interaction mechanisms. Then in stage three we observed how the user reacted in this attention-critical interface situation (driving while operating an information system) to the changed system.

4.2.3 RESULTS

In the first stage of the user test all users chose the touchscreen over the multifunction knob when they had the free choice while the car was standing. We asked the users why they chose the touchscreen over the multifunction knob. All users answered that they think it is faster. Regarding the impression from the first user test, the users seemed to have the right feeling here. 4 users stated to prefer the direct manipulation of the letters on the screen to the sequential input via the multifunction knob. 2 users stated that they were used interacting with touchscreens. Altogether these answers correlate pretty much with the results from the first user test.
Half of the users declared, that they had no or just little trouble with entering a destination into the system. The other half of the users declared, that they had problems with the input of data into the system while driving.
An interesting question was how people would react to the system that suddenly constraints users option for action. All users expected that the input via touchscreen would be available while driving. Already the observation showed that users were frustrated when they found out and had to learn and accept that their preferred interaction mechanism was not available in the certain situation. This impression was validated in the interview, where most of the users expressed their frustration verbally (some of them drastically). Users did not like to change their preferred interaction mechanism nor being patronized by the system. All of them expected that the touchscreen would still be available to them. As an improvement some users suggested the concept idea to offer some form of signalization that the touchscreen which text input device is activated and which is not. But generally the users did not like the fact that they were suddenly constrained in their option for action by some contextual parameter.

4.3 CONTEXT-ADAPTIVE INFORMATION DISPLAY

The third user test we conducted aimed at exploring how users react to an in-car information system that changes the way information is being displayed contingent upon the context. We also wanted to find about the users acceptance towards such a context-adaptive system. The relevant context factor was if the user is on the road or off the road with his car. This affected the way how routing information of the navigation system was being displayed. This test was based entirely on qualitative data. The user test took place in an all-terrain vehicle (see figure 5).

4.3.1 EXPERIMENT SETUP

The users in this test were the same six test users as in the test before. While on the road our application showed the usual Sygic Drive navigation system. When the user left the road with the all-terrain vehicle, the usual display of routing information was being substituted by the display of our offroad navigation system. The offroad navigation system showed a compass, a directional arrow (always pointing from the vehicles current position at the air-line distance of the destination) and a satellite photo showing the current position of the vehicle (see figure 5). Instead of detecting the context factor (onroad/offroad) via GPS like in the user test before, we simulated the change of context using the Wizard of Oz technique [13]. Thus the users believed that the system would react autonomously to the change of context but instead the system was actually being changed manually by the moderator of the test.

4.3.2 EXPERIMENT LEAD-THROUGH

Users were being asked to enter a given destination into the navigation system and to afterwards start the drive. The goal of the test users was to reach the given destination. After some hundred meters the moderator of the test told the test user to leave the road in order to take a short-cut off the road. The test users left the road and drove via an offroad track (see Figure 5) towards the destination. In the very moment in which the users left the road, the moderator switched the information display from the usual SYGIC navigation system to our offroad navigation system (see screenshot Figure 5). The moderator did this without notifying the users.

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On the basis of the displayed information test users had to decide on a junction which way to drive in order to reach their goal. After some hundred meters the test users reached the normal tarred road again and the moderator switched the information display back to the onroad system. We observed how the user reacted to the changed information display while driving offroad held an interview after the user test.

4.3.3 RESULTS

Based on our observation during the test and the interview after the test we found out that half of the users noticed the change of information display immediately or after a rather short period of time. The other half needed a rather long time to notice the change of information. The fact that it took some users a bit longer might be caused by that users were distracted by driving a strange all-terrain vehicle offroad in a test situation and also for the first time. All users noticed the change of information display when they had to refer to the navigation system in order to orientate at the junction.

When users had perceived that the information display has changed, all users had to understand the new way information was displayed to them. One user knew this way of displaying routing information from another offroad navigation system but did not like the new way information was being displayed. One user felt unsafe by the fact that the display had changed. According to their statements the other 4 users were rather indifferent to the new information display being busy with trying to understand the underlying concept.

For us the most interesting result from this user test was that after understanding the idea and usefulness of the altered information display users felt positive towards the adapted user interface. Only one user (the one that felt unsafe with the new information display) did not like the idea that the information display changed without being asked before. All other users subjectively liked the fact that information display had changed adaptively to the context.

5. CONCLUSION

The authors explored whether and how context should be an influencing factor for the user interface and user interaction. The carried out rapid prototyping and the following evaluation with real users of a context-aware in-car information system was embedded in an user-centered design process. The evaluation has led to some insights about the attitude and acceptance towards input devices and adaptive systems. There seems to be a strong contrast between the acceptance towards an adaptive information display compared to an adaptive interaction mechanism. Users did not like to change their preferred interaction mechanism nor being patronized by the system. When the interaction mechanism changes (while driving one is not allowed to use the touchscreen and has to use the multifunction knob) users were irritated and sometimes frustrated that they have not been noticed by the system about the adaptation. Signalization (for example an auditory information) that the interaction mechanism has changed might be very useful. On the other hand the change of displaying information (when users drove off the registered track the onroad navigation system switched to an offroad navigation system) was accepted by all users. All users willingly accepted that the way information is being displayed had changed without being asked before. Actually users appreciated an adapted information display when the adaptation made sense to them (e.g. when driving offroad). In this aspect users mentioned that consistency should be provided throughout different contexts (for example the same color code for equivalent objects like the directional arrow).

The authors support an user-centered approach to the design of in-car information-system in order to offer a good usability to drivers. The change of an in-car user interface contingent upon context factors can be very critical, even dangerous. Thus rapid prototyping techniques, an agile development process and the iterative feedback of real users seems helpful to develop usable and safe systems.

6. FUTURE WORK

Currently our system is aware of the context parameters location, speed and driving direction. In the near future we plan to further acquire context data using additional sensors. For example we are just preparing to use temperature and humidity sensors to analyze the context parameter weather and to analyze the noise in the surrounding. Also we think about the implementation of shock sensors to analyze the current track. This sensor might be able to find out whether the user is driving offroad on a bumpy track. In order to analyze the safety and the speed of input devices for entering text (e.g. speech input devices) into an in-car navigation system we are planning to implement and test additional devices with a larger sample of participants.

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