In-car Interaction using Search-Based User Interfaces

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ABSTRACT
Increasing functionality, growing media volumes and dynamic data in today's in-vehicle information systems bear new challenges for user interaction design. Traditional hierarchical and menu-based interaction can only provide limited support while new search-based approaches are promising. In this work we assess different search techniques and search-based user interfaces. In particular we compare free search across all data items with categorized search. Our experiments with functional prototypes show that free search is more efficient and easier to use than searching within categories. Tests in a driving simulator show promising results regarding safety and workload. Means for alphanumeric input appear to be essential for an efficient and safe search interaction while driving.

ACM Classification Keywords
H5.2 [User interfaces]: Interaction styles, D.2.2 [Design Tools and Techniques]: User interfaces, I.3.6 [Methodology and Techniques]: Interaction techniques.

Authors Keywords
car interface, in-vehicle information systems, search-based interaction

INTRODUCTION
In the course of the increasing prevalence of integrated in-vehicle information systems (IVIS) in modern cars designing interfaces is becoming more difficult. To create user interfaces that are pleasant and easy to use while driving without compromising safety becomes an even more challenging task. The functionality and the amount of data for which user interfaces are needed are fast-growing. This comprises navigation applications, communication, music, traffic information and infotainment provided by the car. Today's in-car information systems often include up to 700 functions [10]. Also, more and more drivers connect portable devices, such as phones and music players, with personal data into the car environment. Access to personal contacts, address, and entertainment has become indispensable for many people even while driving. The use of extra functionality implies the task to limit visual, motoric and cognitive workload besides the driving activity [5]. It is essential that interaction in the car must not compromise the safety of the primary driving task. In home or office environments, or even while walking, users can interrupt their primary task. In the context of driving a car however, such an interruption may endanger the driver or the safety of other traffic participants. Many national laws regulate which forms of interaction and which user interfaces are allowed to be used while driving. Accordingly in many countries only hands-free systems are permitted.

To address these new challenges the car industry and research institutions are exploring new options for supporting interaction with IVIS and portable devices while driving in a safe, convenient and lawful manner. One approach is to integrate mobile devices and their functionality into the IVIS. The user interfaces in such systems are designed to work well while driving. Mobile devices are then operated with the controls available in the car and their output is rendered through the IVIS, e.g. visual output will be shown on the car information display, audio output will be played via the car audio system. One common example are mobile phones that are connected via Bluetooth to the IVIS.

Currently most IVIS use a menu-based, function-driven interaction that has evolved over time by adding functions as they became popular. Having increasingly large data volumes (e.g. music collections of several GB) and dynamically changing information (detailed traffic and weather information) menu complexity and usage efficiency could be limited. New interaction techniques, in particular search based ones, offer interesting alternatives.

In this work we investigate the suitability of such search techniques for in-car interfaces in the context of driving situations. Search interfaces have become popular in the desktop and internet world. To explore the suitability of this approach we have created a set of functional prototypes of in-car search interfaces. The prototypes have been assessed in occlusion and driving simulator tests and evaluated in different experiments. The results show that search interaction is indeed useful in driving situations.

RELATED WORK

Menu-based, function-driven in-car user interfaces have to be designed not only with respect to usability requirements, they also have to be suitable for use while driving. Guidelines are given in [6] and in form of Best Practices [2]. Present IVIS use rudimentary search interaction for reducing items in long lists, but not for overall search.

Using search techniques in in-car interfaces has been recently assessed by [1]. They propose that a search agent can help with navigation in deep hierarchies and in huge databases, and consequently has a high potential to increase the concentration on the primary driving task together with high user acceptance. But specific research on in-car search user interfaces is rare.

DESIGN SPACE FOR IN-CAR SEARCH-INTERFACES

The variety of information elements and the multitude of functions need to be structured to create an understandable user interface. In our approach we use an object oriented view of the information items.

An object oriented approach

When integrating additional services and mobile devices in IVIS there are two major challenges:

- dealing with a large variability in available functions and data provided by additional services of mobile devices
- providing compelling and consistent means for interaction based on the in-car controls

As devices vary and new devices become available, it becomes apparent that the functions that have to be integrated are only partially known during the development process of IVIS. As cars typically have much longer life-times than mobile devices, it is an issue which advances in technology do not solve. Functionality and data offered by mobile devices should be accessible while driving. Therefore it is a requirement that the IVIS is able to integrate dynamic data volume. A rigid, hierarchical menu-structure is generally not suitable for this requirement since it can only react with a horizontal or vertical modification of its menu tree. This implies a huge technical expense which means a modification of system interfaces and furthermore a change of the user mental model [6]. Even without the additional services, data and functionality today's IVIS are often perceived to be too complex and difficult to use. This leads to the question: can menu-based systems provide an appropriate solution to these problems [8] or are there other options that are more suitable? The concepts described in this paper address both challenges mentioned above. The approach is to combine object oriented data handling and search based interaction. This is in contrast to automotive UIs that so far operate mainly by function-oriented menu-systems. We treat data from mobile devices as objects providing functionality. This view needs to be supported by the chosen interaction concept.

Interaction concepts

Our initial research indicated that search-based interaction would provide great flexibility and meet the requirements stated above. Initial studies in [1] indicate that users can do search-based interaction while driving. To understand the design space, options, and limitations of search-based interfaces for in-car use we created 16 different elaborated interaction concepts. All were specifically targeted for in-car use and were based on search techniques.

These search-based interaction concepts consist of two parts: input of search terms and presentation of results. Realized as paper prototypes these concepts were shared and discussed with 10 user interface experts. This expert evaluation assessed the strong and weak points, the suitability for in-car use and technical and practical requirements (e.g. screen size and type). Paper prototyping for this step was very efficient and allowed rapid evaluation of graphical prototypes and interactive concepts on the basis of printouts. This process helped to discover severe design mistakes or breaks and flaws in the interaction concepts. The designed interaction concepts were specifically targeted for the in-car use, but partially inspired by techniques used on the WWW (e.g. tabbed browsing, tag clouds), on the desktop (e.g. quick search, categorical search), in other applications (e.g. fisheye scrolling, bubbles, sandbox, 3D) or abstract concepts (e.g. function-driven search, filter-based search).

As a result of the expert evaluation and discussion process the concepts of 'quick search' and 'categorical search' emerged as particularly suitable approaches for an in-car search interface. The most promising designs were then implemented as functional graphical prototypes and evaluated in user studies.

Alphanumeric input

For useful search interfaces it is essential to have an appropriate and efficient alphanumeric input device. In an automotive domain, the challenge is to provide an input device, which is non-distracting and useable with no or little visual attention. Options currently used in cars are touch-screen-based soft-keyboards and A-Z spellers operated by a controller. As an innovative approach, we used an advanced control element for text input. The device is a touch pad that provides hand writing recognition and is integrated in a traditional controller [3]. We use single letter recognition (ART recognizer software) without prediction or completion as we assume an unknown data vocabulary of real data-sets from mobile devices and novel services. Recognition accuracy for a single letter was measured with 85% for destination entry.

PROTOTYPES FOR SEARCH-BASED INTEGRATION

To explore the different options, two prototypes were implemented to compare 'quick search' (QS) vs. 'categorical search' (CS), cf. figure 1 for screen examples.

The QS concept is known from desktop search engines. Users can type freely chosen search terms into a text and the search is unconditionally executed over all available data records. Results are presented in a non-scrollable list consisting of heterogeneous records sorted by a certain criterion (e.g. alphabetically, least/recently used, etc.). Search and result presentation take place in only two steps.

The CS concept requires the input of a predefined data category which the search will be constrained to. After presenting the found search results, the search can be narrowed by entering constraints for further subcategories. Results are presented in a scrollable list consisting of records in single or aggregated form, e.g. one entry for all songs of an album. Search and result presentation can take place in multiple steps.

EXPERIMENTS FOR SEARCH-BASED INTERACTION

Feasibility verification

We designed two series of tests to verify computational and ergonomic feasibility with regard to response time and number of returned results. Each test was run on three differently-sized, typical in-car data sets to allow for varying quantity of data. We chose sets of around 700, 26.000 and 900.000 records which consisted of personal contact information, music files and navigation data. For both tests a set of search words were generated consisting of all potential combinations of characters with a maximum total word length of five characters. All tests were run on standard desktop computer hardware. Since research in the car industry is targeted at a few years in the future, this method is not unusual for preliminary feasibility tests as comparable processing power will be available in cars by the time of deployment.

Average response times showed that almost all search results could be returned within a time of 120ms. The only exception (~ 4 seconds) was found for the one character search on the large data set, due to the large result set.

Another important factor for in-car search queries is the returned number of hits, or more precisely the chance to be able to display all returned hits on a single screen without the need to scroll the results (maximum hits probability). This factor depends on the available number of display rows, which is typically limited to 6-12 in existing IVIS. We found that a surprisingly high percentage of search results can be displayed on a single screen even with only a few character input. Given the small data set (700 records) a three character search query's result set can be displayed completely with a chance of more than 80% on a screen with seven or less rows. Given the medium (26.000 records) or large (900.000) data set nearly 80% of the results of a five character query can be displayed on a 12-row screen. Summarizing can be stated that the response time as well as the number of returned hits of search queries appear to be uncritical for interactive use in the car.

Occlusion test

In order to investigate automotive suitability of the previously determined interaction concepts, we applied the "occlusion" method. ISO standard 16673 [8] describes the occlusion test as a method to evaluate novel in-car interaction concepts for interruptibility and visual demand. In occlusion experiments test persons wear shutter glasses which can be set (in)transparent for defined time intervals (~ 1.5 seconds) while performing a task. Interruptibility is measured by the R-quotient with a value range from 2.0 to 0.5. Result values < 1.0 indicate good interruptibility.

12 participants (9 male and 3 female) with an average age of 43 years participated in our test. Test persons had to accomplish a set of 15 tasks using the described prototypes. Example tasks are: "search a person from the personal contact list", "search a given song", "search all songs of an album by a given artist", "enter a destination into the navigation system", etc. The participants tested the system in two groups in alternating order. The following statements have been hypothesized:

1. Both concepts are suitable for in-car use.
2. QS can be operated faster than CS.

Both concepts show good results with respect to interruptibility which indicates suitability for in-car use. Although 'categorical search' shows better interruptibility (R_2= 0.8065), the participants judged the 'quick search' (R_1= 0.9313) as more usable. The QS approach was also 30% faster on average. A Wilcoxon signed-rank test was conducted stating statistical significance in 7 out of 10 tasks with p < .01, in 1 out of 10 tasks with p < .05, and 2 out of 10 tasks showed no significant differences in favour of the quick search approach (another 5 tasks were carried out for the categorical search approach only). These results indicate

Figure 1: The left screen shows QS where a search term initiates a search over all categories and presents grouped results. On the right CS is depicted. The user can choose the category to which the search term is applied.

an overall superiority of QS over CS. Therefore within the scope of the conducted occlusion study, the previously stated hypotheses could be confirmed.

Driving simulator setup

To better understand QS in a realistic driving situation we evaluated the concept in a driving simulator at the usability lab of a major car manufacturer. We had 20 participants (17 male, 3 female) with an average age of 39.5 years. They had to follow a car at 100 km/h on a 3-lane highway. In this scenario the distance to the lead vehicle and the lane keeping performance are sensitive for driver distraction while operating an IVIS. The subjects had to perform the following peripheral tasks while driving: destination entry, destination from contact, song search, album search, genre artist search and call from phonebook. The assessed variables during the test were total task times, driving performance and subjective workload level.

The total task times allow for comparing existing in-car interaction concepts and for verifying overall usability aspects for in-car use. Compared to total task time for destination entry (54.7s non-distracted /108.8s distracted) of common menu-based IVIS [4], QS turned out to be suitable while driving, cf. Table 1 for test results. As the main task in driving experiments is lane keeping, we measured the standard deviation of lane position while performing the peripheral IVIS operations. None of the variables showed critical values while driving. The variability of the distance to the lead-vehicle was also inconspicuous.

task	**Ø TTT (+/- SD)**	**Ø SWL (+/- SD)**
destination entry	46.04 (8.58)	2.33 (0.77)
destination from contact	26.07 (9.01)	2.11 (0.66)
song search	21.16 (4.58)	1.89 (0.74)
album search	26.32 (7.00)	2.32 (0.89)
genre artist search	32.91 (10.79)	2.70 (0.85)
call from phonebook	22.80 (5.37)	2.18 (0.65)

Table 1. Total Task Time [TTT], (Standard Deviation [SD]), Subjective Workload Level [SWL], (SD) in seconds

After each task participants were asked for their subjective workload level while driving. The scale was set from 1 (weak load) to 5 (heavy load). As shown in Table 1, all workloads are denoted to be moderate and can be considered to be weak workload while driving.

CONCLUSION AND FUTURE WORK

In this work we assessed the potential and suitability of search techniques as an interaction approach for in-vehicle interfaces. An occlusion test and a driving simulator experiment showed promising results. For the investigated tasks, the search approach seems to be equally suitable or superior compared to menu-based interaction in the context of the increasing variability of available functions. The 'quick search' interaction concept appears to be generally faster than the 'categorical search' approach. According to statements from the occlusion study, users generally preferred QS over CS, although both concepts show good interruptibility results in the occlusion experiment. QS also performed well in a driving simulator test with respect to total task time and driving performance.

Future research should focus on detailed investigation of visual demand and cognitive workload during interaction with search-based interfaces while driving. Furthermore, it turned out that if search-based interaction is realized, alphanumeric input becomes very important. Handwriting appears to be a promising approach.

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