Designing a Wearable User Interface for Hands-free Interaction in Maintenance Applications

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***Abstract*— One challenge in wearable computing is the design of proper user interfaces and interaction concepts for applications. This paper discusses the design of hands-free wearable user interfaces and shows an example interface for an aircraft maintenance application. The user interface we present used a wireless data glove for interaction.**

I. INTRODUCTION

In order to achieve user acceptance, the user interface of a computer system and its method of interaction are important parts. However, designing interactive user interfaces that are intuitive and even fun to use is a challenging task. For stationary computers, there exists a wealth of research results and software frameworks and a number of well-established interface classes such as desktop and touch-screen interfaces. For general-purpose mobile systems such as PDAs, desktop-based systems have been adapted and the desktop metaphor is mostly kept up. However, these interfaces are based on the implicit assumption that the user fully concentrates on the user interface, uses visual feedback to control the pointer, and most of the time has two hands available for controlling the user interface. In the desktop situation, he might use one hand for the mouse and the other to push and hold modifier keys on the keyboard. In the mobile situation, he usually uses one hand to hold the device and the second one to control it with a stylus, a keypad, a scroll wheel, or a joystick. These implicit assumptions have important effects. For example, the use of a mobile phone while steering a car is forbidden in many countries with the exception of using both headset and voice-activated speed dialing, thus removing both implicit assumptions of full user concentration and two-handed use. In wearable computing, these implicit assumptions also do not hold. As one of the goals of wearable computing is its situated use, e.g., in a work environment, we neither can assume that the user concentrates fully on the user interface nor that both hands are free. Additionally, limitations of wearable computers, e.g., used head-mounted displays (HMD) or low computation power make user interface development even more challenging [1].

This paper focuses on the question of how to design hands-free wearable user interfaces, i.e. user interfaces that do not force users to hold a device in hand while interacting with the system. The user interface we present will be used in aircraft maintenance. Aircraft technicians will be equipped with a wearable computer, HMD, and a wireless data glove interaction device that offers hands-free operation. The applications focus is on aircraft cabin inspection and repair tasks by utilizing the existing electronic cabin logbook infrastructure. The logbook is used by flight attendants to report defects and system failures in the cabin. More details about the use case are given in [2]. The three main requirements that constrained the user interface (UI) design for the application along with their implications are as follows:

1) **Small and lightweight hardware:** The UI has to be resource saving as small and lightweight wearable computers often offer only limited computation capabilities like e.g. the QBIC belt-worn computer [3].
2) **Hands-free operation:** The UI has to be operated without the need of holding an interaction device either in one or both hands. Therefore, gyroscopic mice or track-balls are not appropriate.
3) **No full attention demand:** The UI cannot use binocular or even large monocular HMDs that would significantly effect or restrict the view field of the technicians. The primary attention of the technician is on the maintenance task and therefore the interaction with the wearable computer must only be a secondary activity.

A. Outline

The remainder of this paper is structured as follows: Section II reviews related work in the field. Section III discusses the advantages and drawbacks of different interaction styles for wearable computing. In section IV we describe the developed hands-free user interface for the aircraft maintenance application. Section V concludes the paper. Finally, section VI points out some future work.

II. RELATED WORK

There are different interaction devices for wearable computing. Beside text-input devices for wearable computing such as Twiddler2 [4] or FrogPad [5] more complex devices for wearable computer interaction were developed. Those devices usually use a set of sensors to recognize the user's input, e.g., by gestures. The GestureWrist [6] is a wrist-watch type input device. It recognizes hand gestures that can be mapped to a set of application control commands. The Fingermouse [7] is a wearable mouse input device that is controlled by finger movements in front of the body.

Also a few special purpose user interfaces have been designed for wearable applications. The interface of the VuMan3 is designed around a dial on the device. The graphical UI reflects the input device and arranges elements in a circle [8]. A similar interface, reduced to eight selectable elements was proposed by Schmidt et al. [9]. KeyMenu is a user interface component created to be used in conjunction with the Twiddler chording keyboard [10]. In [11], Boronowsky et al. showed a list-oriented GUI design that uses a data glove device for explicit interaction and a RFID scanner for implicit location context determination. Data-gloves can be used in many different ways dependent on the sensors integrated. Most of them typically come with build-in tilt or acceleration sensors and some way to trigger actions, e.g., [12].

Besides these concrete user interface implementations there are a few more general considerations about wearable user interfaces and interaction arguing that pointing based interaction paradigms such as WIMP (Windows, Icons, Menu, and Pointing) are not suitable for wearable computing, e.g., [13], [9].

III. ADAPTING INTERACTION STYLES TO WEARABLES

In general, five different interaction styles can be distinguished: direct manipulation, menu selection, form fillin, command language, and natural language [14]. In the domain of aircraft cabin maintenance, menu selection is already used to operate an electronic logbook. Thus, we decided to keep the general interaction style and to transfer it to a wearable computer. What remains is the question, how the menu selection could be designed and what the implications for the user are. Since there are only few established input devices for wearables, no standard method for selecting a specific menu entry can be taken for granted.

To approach the problem, we will evaluate two well-known interaction paradigms in the given context: gestures and direct manipulation. When using gestures, the user has to perform a more or less complex gesture, which is subsequently processed and then the results are presented to the user. Obvious drawbacks of these kinds of interfaces are, that during performance of the gesture, there is usually no feedback on the effects, and that there is no inherent possibility to reverse the effect. In contrast, the central idea of direct manipulation techniques is to provide rapid, reversible, and incremental actions. Thus, the user can directly see the effects of his actions and correct them if necessary.

The primary reason, why a re-evaluation of the mentioned techniques might yield interesting results is that in wearable computing, the primary attention of the user is directed towards real-world tasks. The use of the computer is usually assumed to be a secondary activity. Under these circumstances, the advantage of direct manipulation might turn out to actually be a disadvantage. The drawback of the performance of rapid, reversible, and incremental actions is that during the whole time of the interaction, the attention of the user is bound in the control loop. For example, the selection of an icon with a mouse pointer. During the whole process of moving the cursor to the position of the icon, it is necessary to focus on the pointer. It is very hard to visually focus on another activity at the same time. While performing a specific gesture, it is possible to visually focus on another activity. Gesture interfaces might have another disadvantage instead: If there are a lot of different possible gestures, the user might be forced to think hard about the right gesture and to focus on the correct performance, which might also force the interruption of another activity.

We believe, that the choice of an interaction paradigm for wearable computing is more complex than in desktop computing, because the best choice depends on the context of the application. First, the primary activity of the user has to be characterized: how much visual, auditive, and cognitive resources does it bind? In the next step, a user interface can be designed, which is constrained to use only the free resources of the user.

A. Menu selection with a data glove

We designed a wearable user interface controlled by a data glove which provides both paradigms for the evaluation of the more suitable one for a given situation. In both cases, we constrained the selection to a one-dimensional task (compare [11]). The data glove measures the rotation of the user's hand. Different algorithms are used to translate it to a movement of a cursor on the screen (in one dimension).

In the case of direct manipulation, the rotational angle of the user's hand is directly translated to a position on the screen. Thus, if the user turns his hand fully to the left the cursor is always on one side of the interface, if the user turns his hand fully to the right, the cursor moves to the other end of the interface. Preliminary tests with users reflect the same positive impression, which users reported for other direct manipulation interfaces: They were surprised how easy it was to control the computer, even though the input and output modalities were unfamiliar to them (data glove and HMD). The disadvantage is, that visual attention is bound during interaction.

The same interface can be reconfigured to be controlled by entering gestures with the data glove. For simple navigation, two gestures were defined: One for moving the cursor to the next position and another for moving the cursor to the previous position on the interface. This change resulted in the expected shift of cognitive resources. After determining how many positions the cursor should be moved, the corresponding gestures could be given without further focussing on the screen. Therefore, the effects of the movement of the hand were not that obvious to the users, since the interface did only give feedback after a gesture was fully performed and recognized.

IV. THE USER INTERFACE DESIGN

For building the wearable user interface (WUI) of the aircraft maintenance application the WUI-Toolkit [15] was used. The toolkit provides us with an approach to build WUIs with reusable components in a fast and abstract way.

By specifying an abstract model of the user interface in a task-oriented and visualization-independent manner the WUI-Toolkit is able to provide different levels of automated WUI generation.
For handling the requirements of our application, we implemented a custom layout and interaction manager that suits the plug-in architecture of the WUI-Toolkit. Thus, we were able to use our own custom layout and interaction modules instead of a predefined one of the toolkit.

A. *Interaction Hardware*

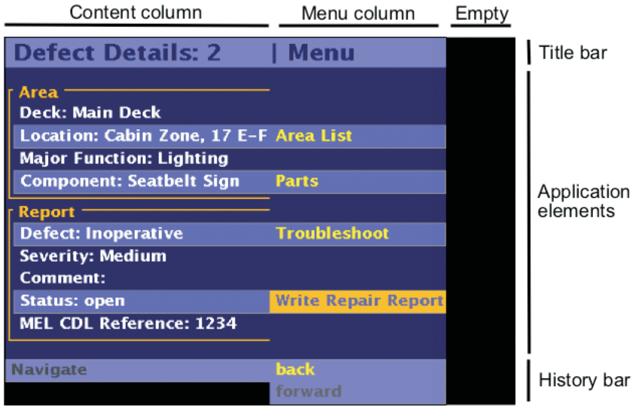
To implement hands-free operation we use a wireless data glove built with a small sensor board. The current version of the data glove features a special wearing concept and is capable of handling different sensor configurations.
The wearing concept is based on three different gloves that build the actual data glove. By changing the outer glove the device can be adapted to specific application domains whereas the inner glove can be used for hygiene aspects. Figure 1 shows the data glove used in our experiments as well as its layer-based wearing concept.

Fig. 1. Layer-based Wearing Concept of the Data-Glove

For designing interaction methods such as gestures or commands, the data glove offers built-in sensors. A liquid two axis tilt-sensor is attached on the back of the hand and allows measurement of the gravitational vector, i.e. rotation angle. Three reed-contacts are positioned ergonomically at the tips of the fore, middle, and ring finger of the glove. They are triggered when the thumb touches the contacts. Moreover, the sensor board features a visual and acoustic feedback system that consists of three different colored LEDs and a small piezo speaker for audio signals.

B. *Visual Components and Layout*

The graphical components of the user interface are designed for a monocular HMD, namely the MicroOptical SV-6. The display provides VGA resolution, a narrow field of view of approx. 16 degrees horizontal and 20 degrees diagonal, and is relatively small. It is expected to be worn out of the visual center, i.e. on the right side on the right eye or on the left side on the left eye, so the user can primarily focus on the real-world task.



Deck: Main Deck
Location: Cabin Zone, 17 E-F
Major Function: Lighting
Component: Seatbelt Sign
Defect: Inoperative
Severity: Medium
Comment:
Status: open
MEL CDL Reference: 1234

Fig. 2. Wearable User Interface Layout

When the display is placed as described, there are again areas on the display, which are more in the visual center and others being more in the periphery. For our prototype, so far we considered only wearing the display on the right eye. Then, the left part of the screen is more in the visual center than the right part and thus more comfortable to see. For this reason, we added some empty space on the right margin of the interface that causes to whole interface to move more to the left and thus more to the visual center of the user's eye. For left-eye usage, the situation is reversed. The elements on the screen are arranged to take this situation into account.

A two-column layout is chosen to take advantage of the situation. The important content – e.g. defect descriptions and troubleshooting instructions – is placed in the left column. As described in the previous section, we reduced interaction to a one-dimensional process. In the graphical interface, this is reflected by interacting with a vertical list of items in the second column on the right side of the screen (see figure 2).
The content column on the left is arranged vertically. Borders are used to create groups of elements. Multiple pages arrange content into blocks fitting on the screen. Visual elements connect specific parts of the content on the left to menu items on the right to express coherence, e.g. the content text "Location: Cabin Zone, 17 E-F" is connected to the menu item "Area List".
A history function is automatically added by the WUI-Toolkit to the bottom of the screen that provides navigation to previous and next dialogues.
In contrast to desktop screen design, a dark background color was chosen (dark blue) with light foreground colors (white and yellow). On a HMD dark colors tend to be perceived as being transparent. A bright background might blind the user. Large fonts (20 pixels) are chosen for comfortable reading on the small display.

C. *Interaction Method*

The data glove measures the rotation of the user's hand. Different algorithms can be used to translate it into, e.g., movement of a cursor on the screen or rotation angles. The

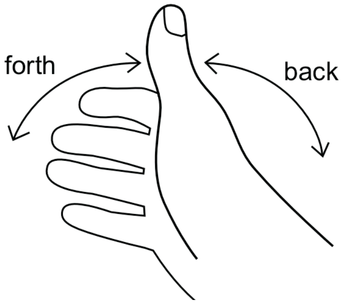


Fig. 3. Gestures Used for Interaction

interaction style supported by the current version of the UI is menu selection [14]. Three different gestures have been defined to control the cursor on the user interface with low visual attention. To navigate *forth* and *back* through the vertical list menu structure, we use intuitive hand-based rotation gestures (see figure 3). Navigating back in the menu structure to select a previous item is done by turning the hand to the right and back to the starting position. To navigate forth in the menu structure and select the next item in list the starting motion is a left turn. As gesture recognition of these gestures does not involve complex recognition tasks it could be easily implemented on the used wearable computer. Although we chose the mentioned gestures there are others that could also be applied as discussed earlier.

For example, in the case of direct manipulation, the rotational angle of the user's hand could be directly translated to a position on the screen or scrolling speed and direction.

A third gesture similar to a mouse click was used for *selecting* items. By bringing together the data-gloves built-in reed-contact at the ring finger and the magnet at the thumb a selection is triggered. For preventing unintentional selections, we do not chose the pointing or middle finger for activation although they are more easily reachable by the user, because in the natural posture of the hand thumb, forefinger, and middle finger are often close to each other or even in touch. The recognition of the gesture is done by observing the ring finger's reed contact state.

V. CONCLUSION

This paper discusses the design of a menu selection based hands-free wearable user interface. It shows the implementation of an interface that requires only low visual attention. As an example we considered the domain of aircraft maintenance. A wireless data glove was used for gesture-based interaction with menus. The actual design of the user interface shows that interaction, layout and used devices of a UI are strongly related. In particular, we discussed the implications of used hardware and the computer not being the primary task. For example, the positioning of the list navigation right besides the content on the left reflects the intended use of a data glove that is worn on the right hand and the HMD worn on the right eye in our interface design. More general, we argued that the best choice of interaction paradigms in wearable computing strongly depends on the context of application the user interface is developed for.

VI. FUTURE WORK

Although the user interface was designed along the requirements of the application domain there are more improvements and evaluations needed. Therefore, the future work includes user studies to evaluate the chosen design and interaction concepts. In particular, we will evaluate the different interaction styles for menu-selection to get deeper insight which style is the most suitable one in wearable computing maintenance applications. Moreover, the evaluations should also investigate performance issues to show, how appropriate selected interaction techniques are for daily use of novice, intermediate, and experts users.

Another topic beyond evaluation is to generalize the findings of the studies to formulate guidelines or rules that could be used as a reference for future wearable user interface development.

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