A Toolkit for Context-aware User Interface Development for Wearable Computers

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***Abstract*— This paper proposes the design and implementation of a toolkit for creating wearable user interfaces with reusable components. The toolkit is based on a model-driven approach that builds on an abstract model of the required user interface for an application. By using available context information of a wearable system, the toolkit supports context-aware user interfaces that adapt themselves.**

I. Introduction

User interfaces (UI) are a central part of every application. They must ensure appropriated usability and information presentation in order to let users control the application. When concerning wearable user interfaces (WUI), this becomes even more challenging [1]. Limitations of special I/O devices used for interaction or presentation in wearable computing (e.g. HMD's, data gloves) strongly vary from devices used in stationary or mobile computing, where WIMP (Windows Icons Menus Pointing) interfaces dominate. Additionally, operating wearable applications is often a secondary task, i.e. most attention of the user is paid on primary tasks, which requires special user interruption concepts. As a consequence, known design guidelines, usability constraints, and available UI widget libraries for WIMP interface development are not applicable. Clark [2] also confirms this by stating that the "desktop metaphor is dead" for wearable computing. However, today, no guidelines or standards for wearable user interface development exist. Instead, special purpose interfaces were designed that require special input devices and often graphical output devices (e.g. [3], [4]). However, such individually designed interfaces have the drawback that they are not easily reusable in other configurations. And thus, can not be used to reduce implementation efforts for WUIs. A first attempt to standardization is currently done by the wearIT@work project [5] that aims to build a framework for wearable application development.

The Wearable User Interface Toolkit (WUI-Toolkit) proposed here aims to provide a toolkit for WUI development with reusable components. It meets the special requirements of wearable computers and takes, e.g., context information of a wearable system into account if available. Thus, the goal is to develop a middleware for supporting the implementation of context-aware WUIs without limiting them to graphical user interfaces or specific interaction devices.

A. Outline

The remainder of the paper is structured as follows: Section II reviews related work for a proposed WUI-Toolkit. In section III basic requirements to be considered for the development of a WUI-Toolkit are presented. Section IV gives an overview of an architecture of a WUI-Toolkit, whereas section V identifies open research challenges of the toolkit. Finally, section VI concludes the paper and presents future work.

II. Related Work

Creating reusable context-aware UIs for applications is a complex process. It might include the design and choice of suitable UI components, the processing of observed context events, and the rendering of UIs. The Context-Toolkit [6] has been proposed for the general integration of context into applications.

When WUIs should be used on a wearable device, obviously WUI components and interaction concepts are needed. 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 [7]. A similar interface, reduced to eight selectable elements was proposed by Schmidt et al. [8]. In [3], Boronowsky et al. showed a list orientated GUI operated by a special data glove device. KeyMenu is a user interface component created to be used in conjunction with the Twiddler chording keyboard [4]. What is common to all these user interfaces is their dependence on special input devices which make any further reuse difficult.

Besides the mentioned wearable interaction devices there have been developed more. The GestureWrist [9] is a wrist-watch type input device. It recognizes hand gestures that can be mapped to a set of application control commands. The Fingermouse [10] is a wearable mouse input device that is controlled by finger movements in front of the body.

To compose user interfaces for different devices, model-based approaches that describe interfaces from different perspectives have been developed. Here, task models have gained much acceptance, as they support the construction of UIs for different devices in a task oriented and interaction centered manner [11]. The ConcurrentTaskTree (CTT) notation [12] is widely used to describe such task models in a hierarchical tree structure.

For describing UIs in a platform independent way, there are different markup languages. For example, the User

Interface Markup Language (UIML) [13] addresses this issue. It supports a declarative description of a UI in a device-independent manner. However, it does not support model based approaches well, because it provides no notion of tasks. XIML [14] (eXtensible Interface Markup Language) also supports a device independent UI description. It provides a mechanism to completely describe the user interface, its attributes and relations between elements of the interface without paying attention how they will be implemented.

III. Requirements

The requirements of the proposed WUI-Toolkit as envisioned above are described in the following.

- *Ease of use and component reusability*
  The toolkit should facilitate the development of WUIs and reuse of its components. By providing the toolkit with a specific abstract model of the needed UI a WUI should be generated.
- *I/O device independent UI description*
  For describing UIs in the design phase independently of any specific wearable I/O devices and modalities, an abstract model of the UI must be supported. This model should be defined in a task oriented manner by an abstract UI description language, as most wearable applications are task specific rather then general purpose, e.g. [3].
- *Distribution of toolkit components*
  Limited computing resources of wearable computers, such as battery capacity and CPU speed, require the possibility of distributing application parts. The toolkit should feature such distribution capabilities for its core components. Especially, the possibility to run the abstract model management on one system and the UI rendering on another system should be supported.
- *Special UI components and interaction concepts*
  The toolkit should provide a basic set of user interface components and appropriated interaction concepts. These components must be suitable for operation with different interaction device classes and must be designed for wearable computing.
- *Support for multi-modal interaction*
  To achieve unobtrusive and situation dependent interaction with a WUI, generated user interfaces should not be limited to graphical output. Instead, the toolkit should support basic service for multi-modal interaction, at least for combining graphical and audio interaction.
- *Integration of Context*
  Wearable computing is strongly related to context recognition. Therefore, WUIs generated by the toolkit should use recognized contexts of a wearable system to support basic context-awareness. Since, there are already context frameworks available (e.g. the Context-Toolkit [6]) the WUI-Toolkit should provide an interface to such systems.
- *Adaptation Component*
  For allowing the generation of WUIs that automatically reconfigure their operation concepts or appearance in a certain situation, the toolkit should feature a reasoning component in conjunction with a rule base. This component should manage an extensible adaptation rule base and should implement an appropriated reasoning mechanism.
- *Usability of generated WUIs*
  Because the toolkit aims to provide WUIs upon an abstract model, it must be ensured that resulting WUIs are usable.
- *Extensibility*
  Although it is envisioned to have a toolkit with components for handling most common application requirements, it is still desirable to allow an extension or customization of existing components. The toolkit should also support the integration of new available interaction devices to control existing UI components.
- *Compatibility*
  Because wearable computers often do not offer the latest state-of-the-art software packages available, the toolkit must prevent from using latest third party libraries. For example, the availability of special system dependent libraries or software versions should not be assumed.

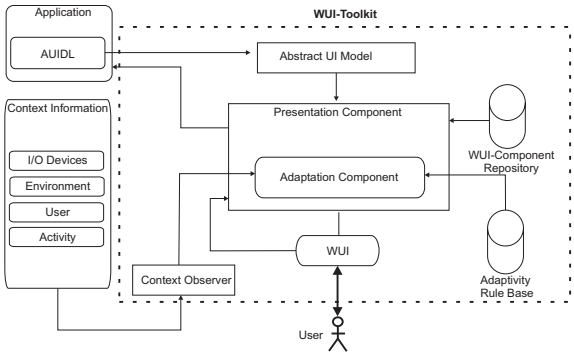

Fig. 1. WUI-Toolkit architecture

IV. The WUI-Toolkit

This section describes preliminary design decisions made on a WUI-Toolkit that meet the requirements discussed above.

A. Architecture Overview

The general design of the WUI-Toolkit follows an event driven approach. Figure 1 shows the basic components of the architecture. The *Abstract UI-Model* handles the abstract specification of requirements of the WUI to be generated by the WUI-Toolkit. It is composed by the application developer and specified by an abstract user interface description language (AUIDL). The *Presentation Component* interprets the UI model in an iterative process with the support of other components in order to construct the actual WUI for the current device configuration and context of use. The *WUI-Component Repository* provides a library of special designed WUI components (graphical and audio). It can be queried with an abstract UI component to identify suitable WUI components. Results are forwarded to the *Adaptation Component*

that selects and customizes the components under available context information and constraints given by the *Adaptivity Rule Base*. After this, the final WUI will be available. When the WUI is delivered to the user, the *Context Observer* observes available context sources by interfacing a context infrastructure, e.g., provided by the Context-Toolkit [6]. The *Context Observer* notifies the *Adaptation Component* about relevant context changes in order to adapt the WUI if needed. User interaction is forwarded by events to the *Presentation Component* whenever performed. Then, the *Presentation Component* fires corresponding application events.

V. Research Challenges

After having discussed related work, requirements and the design of a WUI-Toolkit, this section identifies research challenges. Although in [1] the development of WUIs was identified as generally challenging, there can be identified more specific research challenges when trying to realize the proposed WUI-Toolkit. In particular many questions arise on the WUI adaptation. These include among others:

- *The description of an ideal WUI*
  The question of what are the properties of an "ideal" WUI must be investigated to identify a measure of quality for WUIs. Such a measure could be important for the adaptation process, e.g. if adaptation is handled as an optimization problem. Although, for desktop computers there are already norms, style-guides, etc. that allow the definition of such a measure, they are hard to apply to wearable computers.
- *Robustness in adaptation*
  When dealing with adaptive UIs on wearable computers where context information changes frequently, the question must be investigated when and how strong context changes can modify the WUI without risking a loss of usability or confusing the user.
- *Dealing with informal information*
  Guidelines, usability constrains, etc. are often informal, as they are usually described by descriptive language. When translating these information, e.g. into reasonable adaptation rules, methods must be found that are capable of dealing with these qualitative, fuzzy, and uncertain information. Thus, the question arises, which suitable methods for adaptation can be identified and how they can be combined.
- *Formalization*
  An appropriated formalization of a WUI and the adaptation process seems to be necessary to integrate existing reasoning techniques more easily.

VI. Conclusion

This paper proposes the implementation of a user interface toolkit for wearable computing. The toolkit's approach is to initiate a standardization process similar to existing GUI-Toolkits for WIMP user interfaces. It facilitates the development of WUIs and allows the reusability of WUI components in different applications.

By integrating context information into WUI components, WUIs can be developed that automatically adapt themselves to provide the most valuable WUI under a certain context. The basis of the toolkit is an abstract model of the required UI that acts as an API from the developer's perspective to build the actual WUI for a wearable application.

Concerning the realization of the WUI-Toolkit, the paper discusses arising research challenges. In particular, different open questions were identified on the adaptation of WUIs that need further research to be answered.

Although some initial implementations of the basic architecture of the WUI-Toolkit have already been done to show its feasibility, there is still more work to do. Besides the discussed research challenges this includes:

- The detailed specification of components for modelling the abstract UI.
- The integration of context frameworks for accessing context information of a wearable system.
- The definition of a basic set of adaptivity rules for WUIs.
- The evaluation of generated WUIs concerning their usability.

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