Meeting the Needs of Diverse User Groups: Benefits and Costs of Pluggable User Interfaces in Designing for Older People and People with Cognitive Impairments

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ABSTRACT

"Pluggable user interfaces" is a software concept that facilitates adaptation and substitution of user interfaces and their components due to separation of the user interface from backend devices and services. Technically, the concept derives from abstract user interfaces, mainly in the context of device and service control. Abstract user interfaces have been claimed to support benefits such as ease of implementation, support for user-centered design, seamless user interfaces, and ease of use.

This paper reports on experiences in employing pluggable user interfaces in the European project i2home, based on the Universal Remote Console framework, and the Universal Control Hub architecture. In summary, our anecdotic evidence supports the claims on the benefits, but also identifies significant costs. The experience reports also include some hints as to how to mitigate the costs.

Keywords: Pluggable user interfaces, Universal Remote Console (URC), user interfaces for older people, User Centered Design (UCD), remote control

INTRODUCTION

Today, home devices and appliances come with user interfaces that are either built into the devices or are dedicated remote controls. For example, a washing machine has built-in dials and knobs to select the wash program parameters and start or stop the washing process. Additionally, a display may be integrated into the appliance providing status information. All these controls are built into the washing machine - the user cannot take them away in order to control the appliance remotely.

Some home devices have a remote control in addition to a built-in user interface. This remote control is dedicated to the device or service it controls. For example, a DVD player usually ships with an infrared remote control, in addition to the buttons and small displays on the device itself. The user can choose between either the dedicated remote control or the built-in user interface to control the DVD player. However, they cannot use the TV's remote control to get a DVD playing.

Universal remote controls are advertised for being the solution to the problem of having too many remote controls at home. Certainly, infrared-based universal remote controls are an improvement to dedicated remote controls since they allow controlling a variety of devices from a single ("universal") controller. However, universal remote controls have to be programmed prior to usage in order to know the infrared codes of a particular device. Moreover, they cannot provide feedback on a device's current state, such as whether it is currently on or off. Some advanced universal remotes, such as the high-end Logitech Harmony products, make guesses about the device state, but this is not always reliable.

Pluggable user interfaces allow the user interface to be adapted or substituted for one or multiple devices and services to be controlled. We refer to "pluggable user interfaces" as an architectural concept in device/service control that separates the user interface from the backend functionality in software, and sometimes in hardware (Zimmermann & Vanderheiden, 2007). An abstract user interface or "user interface model" is established as the dividing line between backend application (devices/services) and frontend application (user interface).

A similar mechanism is provided by modern programming languages, such as Java, through the concept of interfaces and the ability to substitute an object at runtime by another object that implements the same interface. However, in the area of user interfaces the concept of "pluggability" at runtime is not present in today's typical development environments.

Following the pluggable user interface approach, the user interface of a device or service is exchangeable, and can be attached or detached at runtime as appropriate. For example, for controlling a DVD player, one user might use a PDA with voice interaction, and another might use an infrared remote control for navigation between the DVD controls on a TV screen.

The pluggable user interface concept supports a wide range of user interface needs and preferences. One device/service implementation, providing an abstract user interface, can host different versions of pluggable user interfaces, in order to serve different users in different usage contexts. This is particularly useful for user interface design for elderly users and users with cognitive disabilities who represent diverse groups of users with regard to their user interface needs and preferences.

BACKGROUND ON HCI AND AGED USERS

BACKGROUND ON ABSTRACT AND PLUGGABLE USER INTERFACES

The idea of abstract user interfaces goes back to the "Seeheim model" (Pfaff, 1985) which defines an application interface model as the interface between an application and its presentation and dialog control modules. User Interface Management Systems (UIMS) have implemented this model in the 80s and 90s, thus facilitating separate design processes for user interfaces and application functionality.

In the late 80s, the "Model-View-Controller" software design pattern was introduced by the Smalltalk-80 programming environment (Krasner & Pope, 1988). In the MVC approach, implementation responsibilities are clearly separated between the following components: The model contains the functional core of an application, the view displays information to the user, and the controller handles user input. The popular "Document-View" design pattern (implemented in many user interface toolkits today) is a variant of MVC in which view and controller are collapsed into one component.

Numerous projects and systems have explored the concept of abstract user interfaces, also often referred to as "model-based user interfaces". More recent examples include the SUPPLE project (Gajos & Weld, 2004) and the Web-based form technology XForms (W3C, 2007). SUPPLE claims to generate an "optimal" user interface for a specific user and their characteristics, employing a constraint-based optimization mechanism. XForms defines a set of "form controls" that can be used to specify abstract user interfaces for forms on the Web.

The Pebbles project (CMU, 2009) at Carnegie Mellon University has investigated how handheld computers and smartphones can interact with personal computers and electronic devices such as a light switch, a photocopier, a stereo or a telephone. The "Personal Universal Controller" (PUC) (Nichols & Myers, 2003) generates a control interface on a PDA, based on the parameters of the controlled device, taking into account the properties of the PDA and user preferences. The control interface has also been demonstrated with an extension for speech input (Nichols, J., Myers, B.A., Higgins, M., Hughes, J., Harris, T.K., Rosenfeld, R., & Litwack, K., 2003).

These and other research and development efforts have shown the feasibility and utility of the abstract user interface approach. However, they focused on the generation or provision of user interfaces by a single party, typically the manufacturer of the device or service. What was missing is the explicit and practical capability for a user or a third party to substitute an existing user interface by an alternate or "pluggable" user interface based on a publicly acknowledged standard.

To address these shortcomings, the Universal Remote Console (URC) framework (ISO/IEC, 2008) was developed and has been released as a 5-part international standard (ISO/IEC 24752) in 2008. It defines a "user interface socket" (short "socket") as the interaction point between a pluggable user interface and a target device or service. In the context of URC, pluggable user interfaces are either generic, .i.e., generating a user interface based any socket description, or specific to a socket, i.e., relying on hard-coded knowledge about the socket.

The URC technology is an open user interface platform, allowing third parties to create a pluggable user interface and use it with any device/service that exposes its functionality through a socket. The framework includes a "resource server" as a global market place for any kind of user interfaces resources to be shared among the user community. It is expected that, supported by a growing community, this will eventually result in a global URC ecosystem, enabling an open competition on user interfaces that will allow the user to pick the user interface that is most appropriate for their characteristics and particular use of context.

Work on URC started in the 90s at the Trace Center at the University of Wisconsin-Madison, with the "universal remote console communication protocol" (Vanderheiden, 1998), resulting in the creation of the V2 Technical Committee at INCITS in 2000. V2 developed the URC standards which were later released under ANSI (in 2005) and under ISO/IEC JTC1 (in 2008). Further work by Trace and the URC Consortium (URC Consortium, 2009) resulted in the development of implementation guidelines and other derivatives of the URC technology. The "Universal Control Hub" (UCH) is a profiling architecture of the URC framework, with the UCH acting as URC-conformant middleware between devices/services and controllers that do not support URC technology (Zimmermann & Vanderheiden, 2007). The UCH architecture has been adopted by multiple projects in Europe, including i2home (i2home, 2009). The architecture has already been implemented in a broad spectrum of applications, with the goal of making them accessible to all users. Implementations include areas such as mobile devices, consumer electronics, interactive TV (Epelde, Carrasco, Zimmermann, Bund, Dubielzig & Alexandersson, 2009), and home security.

For a more thorough overview of abstract user interface approaches and their history, refer to (Myers, Hudson, & Pausch, 2000; Trewin, Zimmermann, & Vanderheiden, 2004).

BENEFITS AND COSTS OF PLUGGABLE USER INTERFACES

Pluggable user interfaces (which are based upon abstract user interfaces) claim to bring about benefits for system implementers, user interface designers and end users. Some of the benefit claims are:

1. **Ease of implementation of personal user interfaces.** Personalized user interfaces (that are a substitute to the "standard built-in user interface") can be implemented in virtually any technology, but the pluggable user interface approach is specifically designed with the goal of facilitating adaptation and substitution of user interfaces (Trewin, Zimmermann, & Vanderheiden, 2004). The effort for adding a personal user interface is relatively low since it is limited to creating a new pluggable user interface (frontend) for the abstract user interface; the implementation of the abstract user interface and its binding to the backend device/service is shared by all pluggable user interfaces for a device or service.
2. **Support for the user-centered design process.** Due to separation of user interface and backend functionality, abstract user interfaces are well suited to be used in a user-centered design process (Trewin, Zimmermann, & Vanderheiden, 2004). Human factors experts and designers can create pluggable user interfaces, evaluate them and make changes on them based on early feedback from the users. Concurrently, device and service providers can implement the backend functionality in an incremental fashion.
3. **Seamless user interface, spanning multiple controlled devices and services, in heterogeneous device and service networks.** A pluggable user interface can span multiple devices and services since it is hosted on a remote device (controller) that is different from the devices and services that are being controlled (Zimmermann, 2007). For example, a pluggable user interface may offer a "watch DVD" task whose execution would involve multiple steps on various devices (which may require different control technologies such as infrared, serial or UPnP): Switch the DVD player on and play; switch the TV on and set input source to DVD player; switch the receiver/amplifier on and set input source to DVD player. In contrast, for built-in user interfaces (or remote user interfaces that are dedicated to one device), the "seam-full" user interface would consist of separate control interfaces for every device involved. In the example given above, there would be three separate user interfaces (one for the DVD player, one for the TV, and one the receiver/amplifier), and the user would have to switch between the interfaces (controllers) to execute the steps of the task.
4. **Ease of use of pluggable user interfaces.** Pluggable user interfaces have been shown to be easier to use than built-in or standard remote user interfaces (Nichols & Myers, 2003). This

can be explained by the following reasons: First, a generic controller typically offers more screen estate and/or more and larger buttons than most devices and dedicated remote controls. Second, a pluggable user interface may be personalized to exactly fit the preferences and needs of a particular user group. Third, the separation of backend and frontend code facilitates a separation of programming and design activities (Zimmermann & Vanderheiden, 2007). Programmers can focus on writing the code for the device/service and its abstract user interface, and don't need to "mess up" with user interface functionality. Human interface experts can focus on good user interface design that doesn't require deep programming expertise and network-specific knowledge.

Obviously, the pluggable user interface concept also comes with costs, some of which are:

1. **Increased effort for first implementation due to technology learning curve.** It is clear that development efficiency is initially hampered by the modeling language and other implementation requirements of model-based user interface technologies (Myers, Hudson, & Pausch, 2000). However, it is expected that the time investment into the technology is recouped soon once the programmers and designers have understood and gained experience in its implementation. Also, the employment of suitable development tools, if available, should greatly expedite the introduction of the pluggable user interface technology in projects.
2. **Early freezing of user interface model.** Early in the development process, backend programmers and frontend designers need to agree on the specification of an abstract user interface. (Note that this freeze applies only to the (abstract) user interface model, and not to the (concrete) pluggable user interfaces.) Changes to the user interface model at a later stage will trigger increased development costs. This can become a burden for projects using an iterative or agile development process. However, this problem is not necessarily unique to the abstract and pluggable user interface approaches. In general, changes to the backend will cause changes to the user interface, and the later the changes happen, the more expensive they will be.

PLUGGABLE USER INTERFACES IN THE I2HOME PROJECT

i2home ("Intuitive Interaction for Everyone with Home Appliances based on Industry Standards") is a 3-year European project in the area of Ambient Intelligence, funded by the European Commission. Its goal is to make devices and appliances in the digital home more accessible to persons with mild cognitive disabilities and older people. i2home follows a user-centered design methodology, with a diverse set of users with regard to their age, region of living, abilities and user interface needs and preferences. i2home adopted Cooper's persona approach (Cooper, 1999) to represent users in various stages of the development process.

Technically, the project is building upon the Universal Remote Console (URC) framework (ISO/IEC 24752), and in particular on the Universal Control Hub (UCH) approach. This technical foundation has been chosen because of its perceived benefits with regard to a heterogeneous set of users. The URC/UCH technology was deemed to be suitable for designing very different user interfaces for different user groups, following a user-centered design process.

In the following, we describe the experiences of the i2home partners in using the URC technology for the design of user interfaces for (1) elderly people in Prague (Czech Republic), and (2) Alzheimer patients in San Sebastián (Spain). Following the Universal Design approach, we have also designed user interfaces for (3) middle-aged people with brain injuries (cognitive impairment) in Sweden. These people experience similar problems in using technology as older users do. Anyway, it seems that a universal framework for the development of mainstream user interfaces should support the needs of all users, not only for the elderly. Otherwise it will likely not be adopted by industry at all.

The objective of these three reports is to reflect on the above benefit and cost claims of the pluggable user interface technology, on the background of experiences made in a real project in applying the URC/UCH technology for different user groups. Note that these reports are based on subjective experiences and anecdotic data rather than hard metrics. This is due to the nature of the i2home project and its goal of developing most usable user interfaces in a 3-year iterative process rather than doing a thorough comparison of software development strategies by running multiple complete development threads (which would also have been way beyond the project budget).

Elderly People in Prague

Introduction

At the Czech Technical University in Prague (CTU) several usability tests were conducted, all focused on the UCH technology and especially on the design and usage of user interfaces. The primary target group was seniors of age 65 or older. This group was described by several personas wherefrom two were evaluated as the potential users of the system. The first persona called "Blanka" is a 73 years old woman who lives alone in a small flat. She has no experience with computers. Her performance with regard to memory, vision and hearing is in decline but is nevertheless self-sufficient in her everyday life. She has major problems with new devices like state-of-the-art TV remote control, DVD or digital radio.

The second persona "Arnost" is a 68-year old man who recently retired but still maintains his hobbies and keeps in touch with his colleagues from work. He has gathered some experience with computers during his time at work. He wears glasses, can operate a cell phone and a PDA, but has minor problems with small fonts.

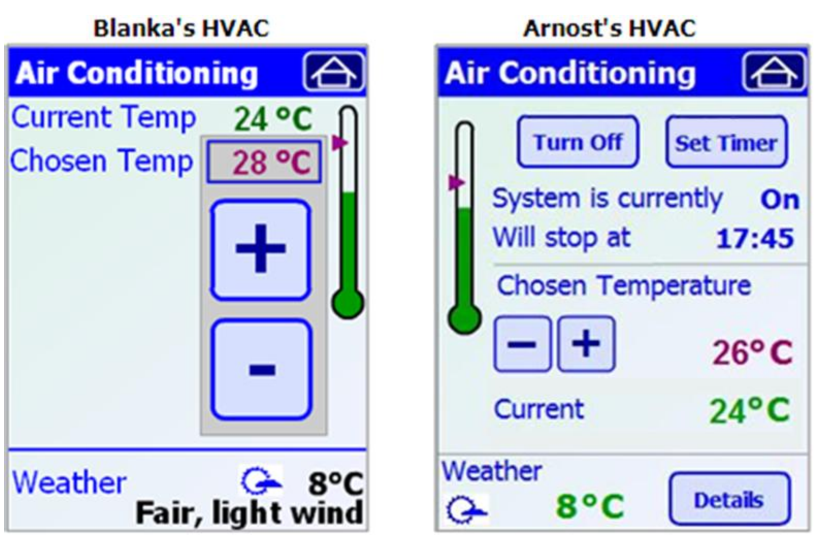

Figure 1. User interfaces for Blanka and Arnost personas.

We designed two different user interfaces, one for each persona. While the user interface for Blanka is simpler and has only the basic set of functionalities, the user interface for Arnost is richer in terms of functionality and slightly more complex in structure. The interfaces were implemented as a combination of a Personal Digital Assistant (PDA) (fig. 1) and a TV.

For evaluation purposes, test participants were recruited for each user interface – 14 for the Arnost persona, and 14 for the Blanka persona. An evaluation of the two user interfaces was performed, based on the objective observations and on the subjective opinions of the participants.

Experiences regarding Benefits and Costs

Based on our experiences drawn from the implementation and evaluation of the pluggable user interfaces for elderly users, we can identify the following benefits and costs of pluggable user interfaces:

- The pluggable user interface architecture was a natural fit to the UCD approach involving personas. We were able to define the requirements of the two selected target groups, implement them as pluggable user interfaces. In our experiments, we could easily interchange the user interface upon determining the most appropriate persona for a test user (Blanka or Arnost).
- The users appreciated the customized user interfaces with a selection of functionalities that matched their needs. For example, users conforming to the Blanka persona required only little functionality from the system.
- The given UCH architecture proved to be useful and appropriate for our implementation. This helped to speed up the development and testing process since we did not have to specify our own architecture.
- During implementation, our developers gleaned knowledge of a device's capabilities by looking at its socket description(s). Thus they could easily check if the user interface covered the whole range of features offered by the device.
- Another benefit we noticed is that the developers could utilize the socket description as semantic hints for user interface design. This could probably have been achieved by other means of documentation as well, but it is an indication that the abstract user interface model is a useful basis for user interface development. In future, we would like to see tools for semi-automatic generation of user interfaces such as for wizards and visual control grouping.
- Learning the technology was a big challenge that was even more difficult because of the early development stage of the platform. Tools for the support of the design and development of user interfaces were not available. However, it should be easy to integrate the pluggable user interface architecture into development environments such as NetBeans or Eclipse.
- Suboptimal design of sockets can make the design and implementation of the pluggable user interfaces difficult for designers. In one case, the initial socket for the calendar system was poorly designed, and its revision resulted in a major effort on re-designing and re-implementing all related pluggable user interfaces.

Alzheimer Patients in San Sebastian

Introduction

Two research centers have cooperated in the following experiment. INGEMA, a research center on elderly and disabled people owned by Matia Foundation Group, has defined the user interface, conducted user tests, and evaluated a prototypical system on a group of 21 test persons with mild to moderate Alzheimer's disease. VICOMTech (www.vicomtech.org), a research center specialized in computer graphics and digital TV, has conducted the technical development.

Both research centers work complementarily on finding new ways to better assist elderly people and especially those with cognitive problems such as Alzheimer's disease. Alzheimer patients, even in the first stages of the pathology, are not able to understand how to operate modern devices or services that could potentially benefit them. Intense research is being carried out in both institutions to identify and validate user interfaces that can be accepted by the target users.

In i2home, the characteristics of the targeted Alzheimer patients were summarized in the description of a persona named "Manuela". Manuela is 73 years old woman who has been diagnosed with Alzheimer's disease three years ago and who now attends a Daily Care Center. Manuela usually forgets to take her daily medication but she is still able to perform simple tasks under supervision. She will become progressively more dependent. Manuela can answer the phone when she hears it, but as dialing causes her problems she tends to avoid it or wait for somebody to help her. Despite her anxiousness to fall, Manuela still goes out alone to make small shopping. However, she usually goes out with her daughter or grandson.

In our experiment, the user interface designed for this particular target group consisted of a realistic virtual character, also called "avatar", rendered on a common television set (fig. 2). This virtual character plays the role of a virtual personal assistant conveying reminders and notifications to the user, and to engage in short dialogs with the user. Additionally, the television remote control serves as a return channel, capturing the user's responses to questions that the avatar raised (Carrasco, Epelde, Moreno, Ortiz, García, Buiza, Urdaneta, Etxaniz, Gonzalez, & Arruti, 2008).

Figure 2. Avatar on TV, interacting with Alzheimer patients.

The results of the evaluation show that, in the majority of cases, interaction with the avatar by means of a remote control was an easy task for the subjects to perform. 80% of the users (n=12) responded to the avatar by voice, in addition to using the remote control, even though no directives were given to that regard. This reflects that this group of people, with mild to moderate cognitive impairment, was able to understand the avatar as an entity with which they could establish verbal conversation as a natural way of interaction.

Experiences regarding Benefits and Costs

Elderly people suffering from mild to moderate Alzheimer's disease are collectively excluded from participating in the information society. The main problem for them is that they don't understand how to use most of today's mainstream user interfaces. In this sense, as stated above, the paradigm of a speaking virtual character delivered on a television was perceived by the users as a natural interaction. Furthermore, the paradigm's usefulness in sending reminders, notifications and in conducting short simple dialogs with the users was demonstrated. The proposed user interface was demonstrated to be appropriate for these users, thus opening the door to a new world of services and assistance opportunities.

Technically, the URC technology and pluggable user interfaces provided a suitable platform in supporting the described user interface, and our experience was that most of the benefits mentioned above were met.

- Ease of implementation: The user interface was easy to implement because it was based on user interface sockets exposed by the UCH. Most importantly, it paves the way to a smooth replacement of the current user interface with other user interfaces. This feature is particularly interesting for Alzheimer patients because, due to their progressive decline of cognitive skills, different user interfaces (each matching a different stage of the disease) could be presented to them without the need of substituting the backend application(s).
- Support for the UCD process: The pluggable user interface approach was found to be suitable to bridge the gap between user needs and devices/services available, because it provides a framework that clearly separates frontend and backend through the definition of the user interface sockets. This division has allowed INGEMA and VICOMTech to concentrate on the definition, development and testing of the proposed "Avatar + TV" user interface, while having other partners in the i2home project work on the backend system and its complexity.
- Ease of use: The user interface proposed in this scenario has been tailored to our target users. In this sense, a simulation of natural interaction between humans was sought, and the results of the evaluations show that it has been readily accepted by mild to moderate Alzheimer patients. Furthermore, no complex information was given to the users through this user interface. Advanced device options or complex settings have been deliberately left out.
- An additional benefit of the URC technology is the reuse of existing user interfaces by other user groups, with possible variations and modifications to cater for subtle differences of users. Apart from Alzheimer patients, we have identified a wide range of other persons suffering from pathologies and conditions characterized by cognitive deterioration and disabilities, such as stroke, vascular dementia, Parkinson-type

dementia, traumatic brain injuries, etc. that might benefit also from the existing pluggable user interface (avatar on TV) for Alzheimer patients.

Nevertheless, there are a number of important costs, including:

- Implementation was significantly harder than in a monolithic approach, mostly caused by the need for learning new technologies, and by the current absence of development tools for pluggable user interfaces and their sockets. On the other hand, this was our first experience with this particular technology. It is expected that implementation of further pluggable user interfaces in the project will be much faster due to the accumulated experience.
- The specification of user interface socket descriptions is a delicate task, and had to be done under supervision of an expert. This was to ensure that socket descriptions would not have to be changed often during the lifetime of the project, which would have triggered increased development costs.

People with Brain Injuries in Sweden

Introduction

For people with brain injuries in Sweden, the German Research Center for Artificial Intelligence (DFKI GmbH) and the Swedish Institute of Assistive Technology (SIAT) have jointly developed a user interface for younger and middle-aged persons with mild cognitive disabilities (Nesselrath, Schulz, Schehl, Pfalzgraph, Pfleger, Stein & Alexandersson, 2009). The typical characteristics of these persons were summarized as a persona called "Emma". Emma is 26 years old, lives with her boyfriend, and used to study at the university. Since a traffic accident with brain trauma, she has to deal with concentration problems and memory deficits. Emma is still very interested in technical devices and tries to use them in her daily life.

Figure 3: User Interface for persona "Emma" - multimodal interaction on a smartphone.

The user interface for Emma consists of a multimodal user interface implemented on an HTC advantage smartphone (fig. 3). The user interface allows for interaction based on gestures with a finger or a stylus, and speech, or a combination thereof. For a description of the underlying technology, see (Schehl, Pfalzgraf, Pfleger, & Steigner, 2008). From a technical point of view, this user interface spans all available sockets that are exposed by the UCH (calendar, reminder, TV, and air conditioning). The main screen features a large pane containing the calendar application on the top. Underneath, a large button (showing a house icon) allows the user to access a list of available appliances; and another button allowing the user to go back to the previously used application (e.g. the TV). The lower part of the main screen is common to all screens: On the left, the button with the curved arrow lets the user return to the previous screen; in the middle, the current time and the battery status is displayed; on the right, the i2home button allows the user to return to the main screen.

The user interface was evaluated with 10 test persons, all with cognitive disabilities caused by brain damage were recruited. Most of the participants rated the different visual parts of the user interface with "good" or better (on a four-choice Likert scale ["bad", "less good", "good", "very good"]).

Experiences

It was possible to implement a user interface based on the URC technology and pluggable user interfaces meeting the majority of the requirements collected in the first phase of the user-centered design methodology. However, in our assessment we have to consider the whole user interface, which is not only composed of the visual display but includes other aspects of the device. With a weight of 355 gram, a size of 133 x 98 x 16 mm, and an LCD display with 640x480 pixels, the HTC 7500 Advantage[i] is quite large for a hand-held device. Although recognizing the advantage of a large screen, some of our participants found the device clumsy and too big for mobile use.

Regarding benefits and costs of the URC technology and pluggable user interface, we have found:

- User Interface Sockets and their descriptions are an effective and efficient means for separation of concerns. DFKI could focus on conceptual and user interface issues, and didn't need to care about the bits and pieces of backend implementation and networking technologies such as for the control of consumer electronics and household appliances.
- The URC technology fits well with the user-centered design methodology, in particular with the creation of consistent user interfaces across all appliances and services.
- As soon as the socket descriptions were defined, it was possible to connect the user interface to simulated targets or services, even though these were not (yet) available. As an effect we were able to start end-to-end testing early in the development process, which clearly improved the quality of the user interface. This is a real timesaver.
- The presence of a formal and explicit description by means of the socket description enables the automatic generation of call stubs. This enhanced the quality of the system in particular early in the development. In general, this increases the comprehensibility of target interfaces.
- The UCH approach allows for easy implementation of a user interface that lets the user control multiple devices and services in a seamless fashion.

- Finally, we have found that the initial learning effort is significant. However, once the team had understood the concepts and details of the URC technology, the benefits were worth the effort.

CONCLUSION

Subjective evidence, based on our experience in the European i2home project, suggests that most of the claimed benefits of the pluggable user interface technology are evident. Most prominently, the implementers agree on the positive impact of URC technology on the user-centered design (UCD) process. Ease of implementation and its positive effects on development efficiency has been confirmed; in particular, where user interfaces had to be replaced swiftly. Further, the pluggable user interface technology is recognized to support the implementation of seamless user interfaces controlling multiple devices and services. In all cases, basic acceptance and usability of the resulting pluggable user interfaces has been confirmed by evaluation evidence. Additional benefits found include the reuse of existing interfaces across user groups, and the ability for early simulation of controlled devices and services.

On the cost side, our experience confirms that the initial overhead for learning new concepts and technologies is significant. One report mentions the absence of development tools as the main reason for this shortcoming. In this context it should be noted that all three development teams had no prior experience and knowledge on the URC technology. Another problem has been identified in the expertise needed for the design of user interface sockets. Poor design decisions in the early phase had led to an unpleasant delay in the project in at least one case. This problem is compounded by the inherent need for freezing the user interface model early in the development process.

Further evidence should be sought for the reported benefits and costs, based on more formal evaluations and objective findings rather than subjective experience. A formal comparison of abstract and non-abstract user interface approaches should be conducted to confirm or refute our subjective findings. However, objective studies may be hard to conduct, since parallel development of whole systems and the employment of a control group seems to be impractical for real projects in the size of i2home.

In this paper, we have reported on subjective evidence for the usefulness of the pluggable user interface approach and the URC technology in a user-centered design process. Much is still to be done, to make the pluggable user interface technology ready for take-up by industry in the development of real products. In particular, there is a strong need for better tool support, including design guidance, in the development and runtime process. Examples include a user interface builder for the development of abstract user interfaces and their pluggable counterparts; and a resource server as a global market place for sharing pluggable user interfaces and their components across users and user groups.

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[i] The HTC 7500 Advantage is sold in Germany by T-Mobile as the "Ameo" smartphone.