Supporting the Design of an Ambient Assisted Living System Using Virtual Reality Prototypes

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Abstract. APEX, a framework for prototyping ubiquitous environments, is used to design an Ambient Assisted Living (AAL) system to enhance a care home for older people. The environment allows participants in the design process to experience the proposed design and enables developers to explore the design by rapidly developing alternatives. APEX provided the means to explore alternative designs through a virtual environment. It provides a mediating representation (a boundary object) allowing users to be involved in the design process. A group of residents in a city-based care home were involved in the design. The paper describes the design process and lessons learnt for the design of AAL systems.

Keywords: APEX, virtual environment, smart space, OpenSimulator, participatory design, rapid prototyping

1 Introduction

Ambient Assisted Living (AAL) systems [1] can improve quality of life if designed appropriately. They can compensate for the potential cognitive and physical deficits of older people without being an obstacle to those who do not have these deficits. The design challenges for AAL systems (ubicomp environments in general, for that matter) are well documented and include: predicting user experience of the system; limiting the cost of deployment that arises through iterating design (an expensive process when building physical environments); minimizing the disruption caused when deploying potentially flawed prototypes simply for testing.

For AAL systems to be successful they must be designed with the participation of their users [2]. Users should be able to explore and experience the system before design and implementation is completed. However, exploring a prototype design of any kind necessarily causes departure from the world that the environment is designed to create. As Weiser commented: “Calm technology engages both the center and the periphery of our attention, and in fact moves back and forth between the two” [3]. The designer should be able to explore system requirements with potential users in a world that does not intrude on these fundamental issues of attention. The problem is made more difficult [4] because older people are a very diverse group whose attention spans are commonly short often because of a lack of interest in the technology.

Rapid prototyping can help to explore a user's experience of a candidate design early in the development process. In principle this can be achieved at minimal cost while at the same time reducing disruption to the target environment. APEX is designed to produce early prototypes of whole environment behavior [5,6]. It provides a framework that combines modeling of the control logic of the devices in a proposed environment with a virtual reality (VR) simulation of the target environment. The platform has also been used as the basis for serious games development [7,8].

This paper describes how APEX was used as the medium of communication in a participative design process for a proposed AAL system in a care home for the elderly. By participative we mean a "concern for the user's point of view" [9]. We show how the prototype environment developed using APEX provided a low cost vehicle to support assessment of the proposed design by providing a vivid experience for participants. The paper offers two main contributions. It describes how: (1) the APEX framework enables rapid development of alternative designs, making design ideas more concrete for participants; (2) a mixed reality environment enables older participants to engage more effectively with the design concepts and to provide constructive feedback about design proposals.

The remainder of the paper is structured as follows: Sections 2 and 3 introduce the APEX framework and the care home, respectively; Section 4 presents the prototype used; Section 5 discusses the participative process followed and Section 6 possible alternatives; Section 7 ends the paper with a discussion on lessons learnt.

2 APEX prototyping

APEX (see [6] for a more detailed description) integrates an existing 3D Application Server (OpenSimulator[4]) with a modeling tool (CPN Tools[5]) and physical devices (e.g. smart phones). 3D application servers, such as OpenSimulator provide a fast means of developing virtual worlds. Because OpenSimulator is open source, it is possible to extend and better configure the tools.

APEX-based prototypes enable users to navigate and interact with a virtual world simulation (through an appropriate viewer) as well as with some of the physical devices of the envisaged ubiquitous environment. A design process is envisaged in which the environment can be gradually made more concrete by substituting actual physical devices for virtual devices. Through the prototypes, users can experience many of the features of the proposed design. The three distinctive features of APEX are that it allows rapid and multi-layered prototyping of ubicomp environments. It provides a 3D virtual environment as a basis for representing the evolving design in a way that can be explored by users through an immersive experience. It also enables the connection of actual devices, as intended for the envisaged ubicomp environment, further improving the immersive user experience and enabling a refinement process, reducing the level of virtuality by gradually populating the environment with physical components.

Several users can establish connections simultaneously, using different points of view in the OpenSimulator server. Users experience the proposed solution as avatars by

[4] `http://opensimulator.org` (last accessed: 2 March 2015).
[5] `http://cpntools.org/` (last accessed: 2 March 2015).

navigating and interacting with the simulation and with each other (e.g. by chat, movement, etc.). The avatar can be controlled by mouse/keyboard, Wiimote or smartphone.

Several ubicomp prototypes, mostly based on existing physical spaces, have been developed as part of the framework's design and development. Examples include a smart library [10,11] and an AAL system aimed at children who are asthma sufferers [6]. The present paper describes the first time the framework has been used to support a design exercise with real users.

3 The Care Home

'Casa do Professor' is a private non-profit social-welfare association aimed at teachers. The organization, which initially provided cultural and leisure services to its members, has gradually extended its scope and today offers a range of services, including continuous professional development and a residential home for retired teachers. The care home is contained in an adapted city-center house in Braga, Portugal. Because it is contained in a historic building, and because the building is multi-purpose, the organization of the rooms and their connection via corridors is complex, making navigation difficult. The ground floor comprises a living room, a dining room and a bar as well as offices and a reception area. The basement comprises an auditorium and other rooms for meetings and workshops. There are also services for the residents in the basement, for example, hairdressing and some medical care. The residents' own rooms are found on the first and second floors.

The house currently accommodates more than twenty residents. A range of support, including medical care, is provided twenty-four hours a day. Many activities offered are provided specifically for residents. Residents may also participate in other activities that are aimed at all members of the association. The house mixes public and private spaces and public and private activities. This requires a degree of openness that can hinder activities designed to ensure the safety of residents. It is not practical, for example, to log those who enter or leave the building.

The aim of the project was to design an AAL system, which could be used to help manage the space and provide relevant services to its users. It aims to cater for the diverse needs of residents, their carers and management. The designed facilities should not be disruptive to the residents' everyday lives. The first stage in designing the environment involved meeting with the institutional stakeholders to obtain their views about what facilities would be useful in the house. These meetings provided the material for an initial design that was later further discussed and developed. The second stage involved a participative design session with a group of residents using the design as developed in the first stage, with its variants, as a basis for exploration. Ideally we would have liked to engage with residents earlier in the process, however management were concerned to keep disruption to the residents' daily routine to a minimum. Additionally we were asked to postpone engagement with residents until such time as a concrete design proposal was available to be discussed.

The four meetings with institutional stakeholders provided material for the basic requirements upon which the initial designs were based. These requirements were:

- knowing the whereabouts of care home residents;

Fig. 1. A physical and corresponding virtual bedroom

- being aware of whether tenants are in their rooms or not;
- providing the means for tenants to call for assistance, ensuring a distinction between urgent and non-urgent situations.

A further meeting established *how* the required services should be delivered to carers and inhabitants. GPS was not possible inside the house and therefore wifi was proposed as a pragmatic though coarse solution. A light by each resident's door was proposed as a means of indicating whether the room was occupied. Buttons by the door were proposed as a means of enabling a resident to call for help. Two buttons were to distinguish between urgent and non-urgent calls. Their location, to be by the door, was agreed upon. These early discussions drove the design of the initial prototype. They prompted consideration of additional features that the AAL system could provide. The complete set of features is discussed in Section 5.

4 The prototype

A prototype was developed to encapsulate and explore the discussed design ideas. It was important that the prototype should support sufficient features of the proposed design and sufficient texture of the environment to enable the residents to experience the systems *as if they were there*.

The proposed AAL system as prototyped included a "virtual home" and an Android smart-phone application using the phone's motion sensor. A virtual world was created to represent one of the floors that is exclusively dedicated to residential use. The floor is composed of ten bedrooms connected by corridors. The rooms are organized around a central stairwell and elevator shaft. Two of the rooms are accessed through a bridge over the main stairs on one side of the building. Pictures of the home's interior and surroundings were used to help develop the prototype, used as memory aids, to guarantee the virtual world was as faithful as possible to the actual house. Figure 1 shows an actual room from the house with its virtual counterpart.

The development of the virtual environment consumed two person days of effort. This effort included the actual development, once the blueprint and photographs were available. In this first version of the prototype each simulated bedroom was equipped with two buttons placed by the door, and a presence light placed outside the room over the door. Adding these features to the model took between two and three hours. This effort included adding each object to the world and specifying its behavior. A mobile Android app was developed. It was designed for use by the staff in the house, so that it was possible to receive notifications from the system if, for example, a button in a room was pressed by a resident. The app indicates the location of an alarm on a house map. The mobile phone's motion sensor was used as a fall detector alerting the staff if its owner falls.

5 Participative design

The prototype was the medium of communication for the design. It was demonstrated, discussed and explored with the house's director, and then with the residents. A focus group was convened that included eleven people associated closely with the care home: nine residents, a psychologist who met this group of residents weekly, and the head of the care home. Two members of the APEX team were involved in the design exploration. One was charged with presenting and potentially iterating the prototype, asking questions and promoting the discussion, while the other took notes, and also engaged in the discussions.

5.1 The focus group

The residents in the group were all in the 70+ age group. They claimed no knowledge or understanding of smart houses or ambient assisted living. It became clear during discussion that residents had no difficulty identifying the environment with the house. They were able to identify which rooms belonged to whom. For example one of the residents became anxious when the demonstrator used the avatar to enter *her* room. As the avatar walked towards the room, the resident first commented that the room belonged to her. When the demonstrator did not understand what was happening the psychologist suggested that he entered the next room instead. This situation was repeated at a later stage, and at that time the psychologist made a signal for the room not to be entered.

Five scenarios were used as illustration. The participants' views, in relation to each scenario as well as the role of the technology presented, were then recorded. Depending on the participants' reaction, questions or further alternatives were put forward. Initially the idea of adding guiding lights to the bathroom was illustrated using the prototype. The residents recognized that going to the bathroom in the dark was potentially difficult. They did not feel the need for lights however because each room had its own en-suite bathroom. Lighting switches were placed by each bed for convenience. A presence light outside each room, indicating whether residents were in or not (see Figure 2), did not stimulate any interest. Our impression was that this feature would be of more interest to staff than to residents. The head of the care home had proposed the idea in an earlier meeting, and had identified as important the need to be aware of the movement and presence of people inside the house (for example, to satisfy health and safety regulations). The open nature of the house and the continual coming and going of people on the lower, more public, floors made this a particular issue.

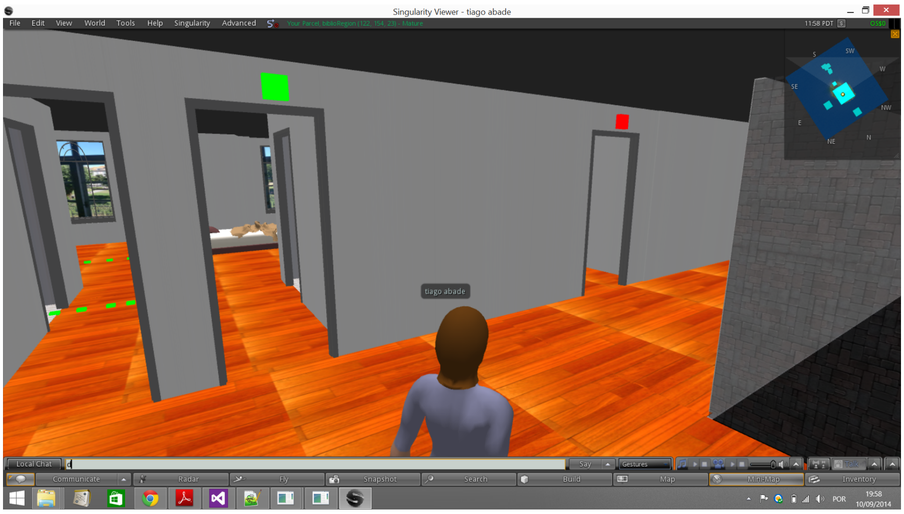

Fig. 2. Presence lights by the doors

The two buttons used to call for help in emergency and normal conditions were illustrated using the prototype. The buttons were viewed negatively by participants. The proposed solution was seen as being too confusing. Some residents were concerned that they would press the wrong button and that rooms already had a calling button. The existing button was however not of the type (or in the position, being by the bed) presented in the prototype.

It was clear throughout the conversation that there was tension between the staff (in particular the head of the house) and residents. Staff wanted to be able to differentiate real distress calls from more trivial ones. This feature was not available in the current system as was identified as an issue during the earlier meetings. The residents on the other hand wanted a simple system that would not compromise their independence.

A further criticism of the button solution related to their position. It was felt that in an emergency the button, positioned by the door, would not be easy to reach. As commonly happens there were conflicting requirements: on the one hand independence was desired; on the other hand there were criticisms of location for a concept that would remove independence.

Presenting residents with AAL technologies using the adopted format risked appearing patronizing, thereby generating negative responses that did not fairly reflect the value of the technology. Our approach was not to present solutions to *their* problems, but rather to ask for their advice and opinion on the envisaged technologies. By empowering the group in this way the risk of offending or patronizing its members was diminished.

The position of the buttons in the room was adjusted to foster discussion of the button placement. Alternatives presented included moving buttons to the WC or closer to the bed (see Figure 3). As the scenarios were presented, the prototype and its envi-

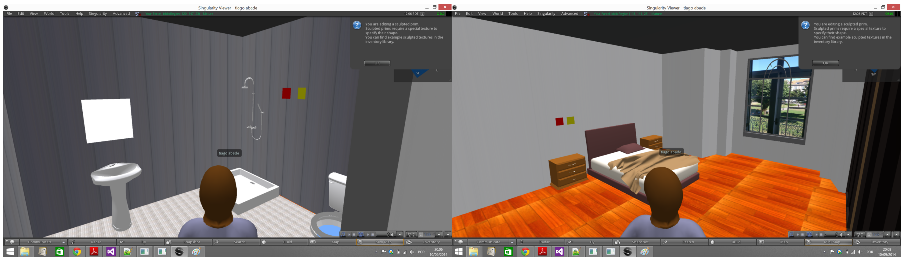

Fig. 3. Discussing the buttons' location

ronment were modified interactively to demonstrate alternatives to the meeting. After some discussion about whether the button by the bed was enough, or whether it should be complemented by another, and where the other should be placed, it became evident that, although at first residents were reluctant to admit it explicitly, providing assistance in the bedrooms was indeed a relevant service from their perspective. While discussing the best positioning of the buttons, one resident explained in detail how she had fallen from the bed and had a very difficult time trying to climb back to reach for the calling button. Example scenarios elicited from the participants provided a rich source of discussion.

Following this productive discussion, the motion sensor aimed at detecting falls was then illustrated. This demonstration used a smart phone that was connected to the prototype. The prototype virtual environment provided in the desktop display was augmented by the smart phone application. The scenario illustrated both how a sensor would be able to detect sudden movements and how the system would then notify carers through the smart phone application. While recognizing this to be a very useful possibility, some residents expressed concerns about how the sensor device would be worn. The possibility of using a bracelet to contain the sensor was well received. Having a panic button on the device was also discussed after suggestion by one of the participants. The discussion generated positive, if not enthusiastic, feedback. However there were also concerns, mostly expressed by the psychologist, about false positives and the types of movements that would trigger the device.

Finally, the idea of the device serving as a localization device inside the house was also explored. Residents were shown how staff members would be able to see their location on a map. The general opinion was that the device would not be very useful in the common areas of the house where other people are present. Someone suggested, with general agreement, that this feature would be most useful outside the house. Residents felt that when they were out in the street they were most vulnerable. It was agreed that the location service should indicate where residents were, whether outside the house or in their room. While administrators were interested in being able to discover quickly where residents were, both to contact them when necessary, and to monitor their well being, the residents focused on their personal safety and of feeling uncomfortable when left alone.

5.2 Updated requirements

The initial requirements were updated based on the focus group feedback. The new requirements combine the original requirements, as discussed with the house administrators, and the views of the house's residents as identified during the focus group. The fact that participants did not use the prototype themselves, but rather saw it being used, inevitably limited the sense of immersion. Discussion by participants revolved around what the house could become, and not about being in the new house. They found it difficult to identify with the possibility that they would live there. Even so, relevant insights were gained from the exercise.

The fact that participants did not (as required by house management) interact with the prototype in person might also raise questions as to whether this type of prototype would be effective when used directly by participants. Issues relating to type of engagement and how to collect data and feedback are important to understanding the value of this type of design. Previous experience, using the framework directly, has shown that engagement is easy to achieve [11,7]. This experience ranges from prototyping existing or envisaged ubicomp systems (e.g. a library or a bar at a theatre), to a serious game aimed at primary school children. Deployment has been mostly desktop/laptop based, but the use of a CAVE environment was also tested successfully.

The environment can also be instrumented to collect information about the behavior of users [7] as they interact with it. In situations were the number of test subjects is high, making direct observation impractical, questionnaires designed to be used after participation have been used. Video recording has also been considered, but so far not used in the absence of appropriate ethical clearances.

A further point to consider is that only the managers and the psychologist were consulted and not other staff in the home. This will inevitably have biased the initial requirements. This omission resulted from the home's internal policy. It did not however hinder our goal of studying the applicability of the approach, and does not invalidate the conclusion that the approach was indeed useful. In future interactions, house staff can be integrated into the process if agreed by the administration.

6 Discussion of alternative approaches

Other examples of form or medium used to support participatory design have included:

Video Video has been used as a prompt in participatory design [4], showing scenarios in which the envisaged technology can be used. Researchers have developed facilities for editing documentary film so that participants can understand and respond to possible design proposals [12,13].

One problem with this approach is a lack of flexibility to support quick reaction to the users' attitudes towards the prototype and input. Using video only it would not be possible to adjust movement in the house in response to specific resident's reactions, or experiment with different locations for the buttons.

Theater Live theater has been used in participatory design [14]. Drama has been used to give texture to scenarios in which a proposed design is intended to be used. An interactive scenario method, including improvisation, and the engagement of participants as actors in scenarios [15], has also been used.

This is an interesting approach. In this particular case, while one of the demonstrators enacted some scenarios through the avatar, and by manipulating the mobile phone, no other participants were involved as actors. However, the combination of virtual reality prototypes with the enactment of specific scenarios by users raises an interesting prospect to be explored in the future.

Paper Prototyping Paper prototyping has been used as a Rapid Participatory Design Technique[16] that enables speedy redrafting and change of design ideas. This approach is less immersive than the other approaches already mentioned. However it provides a mechanism for sketching alternatives rapidly.

Our main concern with paper prototyping was a result of the lack of computer literacy of the residents. Our impression is that paper prototyping is too low fidelity to allow stakeholders to imagine what it would be like to be in the ubicomp environment. However, this is something that requires further work.

Laboratory-based high fidelity prototypes High fidelity prototypes of part of the proposed environment (in this case an ambient kitchen) have been used to provide a physical context in which design ideas relating to the kitchen, and more broadly to other aspects of the environment under design, can be considered [17].

The Aware Home [18] at Georgia Institute of Technology (GaTech) contains two identical floors with nine rooms, each designed to explore emerging technologies and services in the home. The Aware Home team is also exploring the use of a suite in a senior living residence. Their concern is to overcome mobility limitations relating to older adults who might be unable to travel to do their usual tasks.

The issue here is the cost of these approaches, something we address through the use of virtual reality representations of the actual environments.

***In situ* high fidelity prototypes** Building and deploying an initial version of the system could in principle be a feasible option, using recent embedded technologies such as Arduino, but would be too disruptive to the house's operation, and to the residents' own daily routine. It would also mean that exploration of the prototyped system would imply moving about in the house. While this might at first seem to be a better approach, the logistics, and potential for disruption, of such an approach made it less attractive.

A dolls' house A dolls' house has been used as the physical context for considering design issues in an AAL [19,20]. While the house is a rigid design it provides a graphic reminder of the context as design discussion is conducted.

It is possible to think of the APEX developed prototype as a virtual reality based version of a dolls' house, with the advantage of being more dynamic (in the sense that elements in the house can exhibit behavior).

Virtual Reality The advantage of participatory design with virtual environments is the flexibility that it affords. Video, theater and physical dolls' houses all provide barriers to flexibility. However a possible disadvantage of VR is the validity of the feedback obtained when compared with these other approaches. Work exploring the use of VR to assess user experience has indicated that VR is indeed a viable alternative that enables appropriate user experience, see Rebolo et al. [21] when framed by appropriate methodologies. Others have explored the use of virtual reality in participatory design. Davies [22] have developed a VR-based tool developed for participatory design. They argue that this tool can be seen as part of the toolset used by design experts.

Mixed Reality Using mixed reality in participatory design has the advantage that it improves user immersion, enabling participants to interact both with physical and digital objects in real time, potentially enhancing attention span. Bruno et al. [23] use VR with physical devices to involve participants in product interface design rather than ubiquitous environment design. They have demonstrated the efficacy of focus groups in the analysis of virtual products and demonstrated how users can be co-designers using VR prototyping. These results accord with Reich et al. [24] who claim that ideal participation involves customers as co-designers. However, some limitations were identified: i) observing users outside of their daily context may lead to a variation of the modes of interaction with the product; ii) haptic devices cannot be used when interacting with a virtual environment.

The APEX framework makes it possible to change and to explore mixed reality environments, the behaviors of the (physical) smart elements that are part of the design, in the context of possible scenarios. All these elements can be changed and re-presented relatively quickly. We know of no other work, using such a multi-layered approach, that includes the combination of virtual and physical devices in participative design.

Designing AAL services Another perspective that also uses participatory design has been described by Menschner and others [25]. The interesting feature of their work, from the point of view of APEX, is to see the problem as concerned with service design. The APEX framework encourages a view of ubiquitous environments as delivering implicitly a set of services. These services can be characterized in APEX using CPN. The CPN provides a specification that an off-the-shelf service should satisfy or provides a precise characterization of how an existing service should be modified.

7 Conclusions and Lessons Learnt

This paper has described our experience of using APEX, a prototyping platform for ubiquitous computing systems, to design an AAL system. It was shown how the developed prototypes enabled the exploration of the system from the early phases of design. Speedy iteration of the AAL design was made possible by using APEX. While the different components of the design were relatively simple, the system was rich enough to illustrate conflicting requirements between stakeholders. When designing for groups such as older adults care should be taken to find adequate strategies to involve them in the design process. Our design process empowered the stakeholders, and older participants in particular, to engage with the design concepts and to provide constructive feedback about design proposals.

The virtual environment provided good support for evaluation, enabling potential users of the system to help shape it. This supports claims found elsewhere in the literature (e.g. [21]). When exploring the design, differences between the perceptions and opinions of the different stakeholders (director versus residents) were identified. These related to the utility and desirability of the features of the design as well as their interpretation. As a result of the exercise an updated set of requirements were produced to better reflect the interests of all involved. New devices and functionalities were added to the design, while others were removed. This again illustrates how the prototype empowered stakeholders to take an active role in the design of the system.

To conclude, it has been shown that APEX can be used as a prototyping platform for AAL systems, and that these prototypes, in the context of participative design, constitute a useful tool by enabling participants, as co-designers, to explore and contribute to a system's design (cf. [26]). As a result, a design solution will be produced that will enhance their experience of the system and avoid usability pitfalls.

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