APPLICATION OF VIRTUAL REALITY TECHNOLOGIES IN RAPID DEVELOPMENT AND ASSESSMENT OF AMBIENT ASSISTED LIVING ENVIRONMENTS

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ABSTRACT
In the current society, where the group of elderly and people with disabilities is constantly growing, especially due to the increase in life expectancy, it is becoming a must for ICT developers to provide systems that meet the needs of this community regarding accessibility and usability and enhance their quality of life consequently. Ambient Assisted Living, intended to help people live independently, with autonomy and security, is one of the most promising solutions that are coming up to address this technological challenge. This paper presents the approach proposed in the context of VAALID European funded project to make possible real rapid prototyping of accessible and usable Ambient Intelligence solutions, by integrating Virtual Reality simulation tools in the development cycle as well as appropriate user interfaces. The first functional prototype has been planned for March 2010 and will be evaluated during six months in three pilot sites with up to 50 users, starting on May 2010.

Keywords: Virtual reality, ambient assisted living, rapid application development, assessment, accessibility, usability.

1 INTRODUCTION

Nowadays Society is facing a process where life expectancy is gradually but constantly increasing. As a result, the group of elderly people is growing to become one of the most significant in the entire population [1]. This also means that the prevalence of physical and cognitive impairments is increasing in proportion. Elderly people usually suffer from vision deficiencies (yellowish and blurred image), hearing limitations (especially at high frequencies) motor impairments (for selection, execution and feedback) and slight deterioration of their cognitive skills [2]. In this context, providing the elderly and people with disabilities with accessible systems and services that could improve their level of independence, and thus enhance their quality of life, has become a must for ICT developers such as usability engineers and interaction designers. Ambient Assisted Living (AAL) is one of the solutions that are beginning to address this technological challenge.

The concept of Ambient Assisted Living represents a specific, user-oriented type of Ambient Intelligence (AmI). It comprises technological and organisational-institutional solutions that can help people to live longer at the place they like most, ensuring a high quality of life, autonomy and security [3]. AAL solutions are sensitive and responsive to the presence of people and provide assistive propositions for maintaining an independent lifestyle [4].

Within this complex and continuously evolving framework, it is very challenging to technologically meet all users' needs and requirements regarding accessibility and usability along the development process. Accessibility is a prerequisite for basic use of products by as many users as possible, in particular elderly persons and persons with sensory, physical or cognitive disabilities. Usability denotes the ease with which these products or services can be used to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use [5]. These aspects should be taken into account during the product design ideally from early stages, following a more interactive and iterative design-development-testing procedure. The major problem lies in the global cost of the design and development process, which can be critically increased, since AmI solutions involve complex features such as ubiquity, context awareness, smartness, adaptiveness and computing embedded in daily life goods.

Life Supporting Technologies, the research group responsible of this paper, has been addressing for years the convergence of domotics and accessibility. As a result of this process, the group is exploring the application of Virtual Reality (VR) technologies in the process of design and development of accessible solutions for elderly and people with any kind of disability. One of the achievements in this area was the establishment of a living lab at the Technical University of Madrid that allowed the assessment of the user experience of people with disabilities in smart homes using two key technologies: virtual reality and domotics [6].

The living lab integrated a VR application into a real smart home installation. It was configurable for different settings and user profiles, and capable of supporting multimodal interaction through a set of VR and other commonly used devices and displays. The design and implementation process ran under the Design-For-All principles, taking into account concepts such as usability, adaptability, multimodality and standardisation. The living lab resulted in a useful tool for interaction designers and usability engineers to immerse users in a virtual environment and assess, through the application, their experience in terms of interaction devices, modalities and reactions within smart home environments. Based on this assessment, designers would be able to develop new concepts with users, improve existing solutions, and explore, for instance, the possibilities of innovative AAL products and services.

The preliminary encouraging results allowed envisioning multiple possibilities of VR on the process of providing people with disabilities with more adapted access to domotic-related applications. However, this solution had important limitations, especially as it required a significant amount of implementation effort to finally address the assessment of user experience in just one single environment integrating a pre-defined set of products and services.

This paper presents an approach proposed in the context of the European funded project VAALID that extends the key concepts applied in this living lab, providing an easier method to create virtual environments and implement interactivity, enabling dynamic changes of environment conditions and characteristics, and allowing a thorough evaluation of users and real-time interaction techniques. An authoring tool will be developed in order to enable real rapid prototyping and validation of accessible and usable AmI solutions, by integrating Virtual Reality (VR) tools and appropriate user interfaces. This approach will bridge the gap between planning AmI scenarios and their build-up and assessment in reality from the very beginning in the development process, reducing the global design and development effort.

2 VAALID CONCEPT

VAALID is a European research project that aims to develop advanced computer-aid engineering tools that will allow ICT developers, especially those ones that design AAL products and services, to optimise and make more efficient the whole process of user interaction design and to validate usability and accessibility at all development stages, following a User Centred Design (UCD) process.

The VAALID platform will utilise VR technologies to provide an immersive environment with 3D virtual ambient, specifically created for each possible use scenario, where AAL users can experience new interaction concepts and techno-elements, interactively. The usage of VAALID tools will make feasible, both economically and technically, the Universal Design of AAL solutions which have the potential of being acceptable by most persons since their needs are taken into account proactively during the development phases.

The methodology proposed to address AAL solutions is based on a UCD approach, drawing together the practical, emotional and social aspects of people's experience and bringing on the needed innovation that delivers real user benefit. For that reason, the UCD is particularly useful when a new product or service is to be introduced, as it is the case of AAL solutions. The methodology consists of four iterative phases of design, development and evaluation, where both usability engineers and interaction designers must participate, involving AAL users (i.e. elderly and people with disabilities) all along the process [7]:

- *Concept*. First, AAL solution requirements must be extracted, including the functions that the proposed solution provides and how it reacts and behaves, as well as the constraints that should be considered in the design process.
- *Design*. Once the requirements are well identified, developers define the specifications of the AAL solution, taking into account all significant facets that may have influence on the development process. Low-fidelity virtual prototypes of the AAL solution, including 3D virtual AAL-enabled spaces, are built to reflect all aspects of the conceptual design, and further evaluated by users. Design iterations are driven by users' feedback in terms of acceptance and accessibility issues until requirements are met.
- *Implementation*. This phase involves the creation of real and fully functional high-fidelity AAL solution prototypes, with the aim of transforming the validated conceptual design into a concrete and detailed solution. The components developed at this stage must be tested against its accessibility features, and improvements or corrective actions must be addressed accordingly.
- *Validation*. Finally, the implementation of AAL solution prototypes is evaluated and assessed, detecting usability issues both automatically and with potential end users.

This methodology allows virtually simulating each aspect of an AAL product/service and validating it before the real implementation. The whole process involves both virtual and mixed reality elements. The simulation in the design phase requires mainly 3D virtual environments to reproduce the conceptual design of the solution; the implementation phase goes a step further and adds the possibility to use mixed reality elements, so that real functional prototypes can be tested within virtual environments as well.

In order to permit developers to apply this methodology across all the stages of the design cycle, and thus make possible a rapid development of AAL solutions and further assessment with users, the VAALID platform will be structured in two parts: the Authoring Framework and the Simulation Framework. The Authoring Framework will provide the ICT designer with the appropriate components to deal with the three main pillars of an AAL solution, including the creation of user profiles, the modification of AAL-enabled 3D spaces (including sensors, communication networks and interaction devices and functions), the creation of virtual user-interaction devices (which may be embedded in daily life objects) and new concepts for devices and products. These individual components will be afterward validated as an integrated environment in the Simulation Framework.

The VAALID project started on May 2008 and the first functional prototype of the VAALID platform is planned for March 2010. This prototype will be evaluated during six months in three pilot sites (Germany, Italy, Spain) with up to 50 users, starting on May 2010.

2.1 Target Users

VAALID target users can be divided into three main groups:

- *Primary users*: Designers of AAL solutions that will use VAALID as a professional instrument. This group includes *Interaction Engineers*, who design the structure of the simulation, building the seniors' profile and defining the interaction modes with the environment, and *Usability Engineers*, who plan the interface among AAL services and senior citizens, through the study of their interactions with the VAALID system.
- *Beneficiaries*: The main target group of users who will benefit from the results of using VAALID tools. They will be:
  - Elderly people over 60 years old that may have light hearing/sight problems, mobility impairments, or the normal declined cognitive and physical abilities related to age.
  - Young people with hearing/sight/mobility problems, or
  - Any other group of users that may profit from accessible AAL solutions.
- *Secondary users*: All those users that may benefit indirectly from VAALID, using it as a consultancy service. They are:
  - Architects, construction planners, care centres, suppliers of interaction devices, public administration, interior designers and other stakeholders who work for companies that buy and develop AAL services.
  - System designers, who implement AAL solutions validating usability and accessibility of their products, like sensors, actuators or control software.

2.2 Sample Scenario

The potential use of VAALID can be illustrated through the following simplified scenario: A small company specialised in AAL wants to develop a service for detecting fall of elderly people when they are alone at home; if a fall is detected, an alarm is generated and automatically sent to an emergency centre.

Following the VAALID approach (see Fig. 1), an interaction designer creates first a new project in the Authoring Framework.

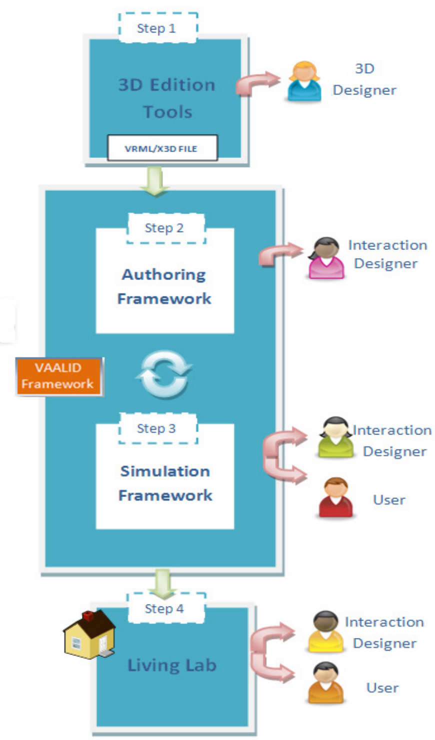

Figure 1: Development cycle proposed in VAALID.

He selects the user profile of a person over 80 with moderate hearing problems, and VAALID automatically limits the possible elements and features consistent with that profile. He imports an AutoCAD model of a house, previously created in an architect studio for the company, and adds to the 3D model all the sensors and objects that will be involved. He also selects from the libraries the service “Fall down” and redesigns this model adding all the needed elements for the service to work properly. In this case, he decides to embed the sensors in a carpet in each room of the house. By running the simulation in the Simulation Framework he can check whether the service has been correctly defined: the service workflow is coherent, the sensors involved are placed correctly around the house, all the features are defined in accordance with the user profile, etc.

Now, the designer requires a real user to test the service in a realistic environment to gather his opinion. In the simulation room, which has been equipped with specialised VR technologies, they use specific glasses to get immersed in the virtual scene of the house. Among the different options available in the simulation room, the designer decides that the easiest way for the user to simulate movements is body gesture. After a short training, the user is capable of moving around and interacts with the house. He lies down in the floor of the simulation room to simulate a fall, and therefore he can experience what would happen in case he had really fallen down, and how the alarm service would react. He asks the designer to change the dimensions and the position of the carpet, and to reduce the time that the system should wait before launching the alarm. The designer sets the new preferences of the user in real-time.

At this point, the service is being simulated in a 3D environment with virtual elements; afterwards, once the concept is fully defined and the prototype of the smart carpet is created, it can be assessed in a more realistic approach through a mixed reality environment. This means that the carpet can be taken out of the virtual scene, and instead, the real prototype is tested by the user at the same simulation room. Thus, enabling the simultaneous usage of virtual and real elements, the service can be validated before the construction of a real living lab.

Several scenarios describing similar possible situations were examined by experts from different profiles, including interaction designers and usability engineers, and their impressions and recommendations regarding the main aspects of the VAALID concept such as working with elderly, 3D and virtual reality technologies have been taken into account for the final definition of the characteristics and functionalities of the Authoring and Simulation Frameworks.

2.3 Authoring Framework

The Authoring Framework [8] is a tool created for interaction designers and usability engineers. Its main objective is to support them to build the core element that composes an AAL service simulation context. The appearance of the Authoring Tool is based on the look and feel of Eclipse (centre stage, properties tab, project browser, etc.) so that an intuitive interface helps the developer to rapidly create the virtual environment where the user moves for tests. It can be personalised and configured to fit the needs of each designer, providing also a help section.

According to the RAD (Rapid Application Development) methodology [9], this tool allows to create a model containing all those templates that will be integrated and then executed inside of the Simulation Framework. The AAL simulation is created from a conjunction of templates stored in a project, the basic component of the Authoring Framework. Every simulation is stored as a single project that is composed of three elements: User Model, Environment, and AAL Service. Each of these elements is created by editing pre-existing characteristics described as properties and behaviour. Properties are defined through ontologies that represent static features of a single model; behaviours are described as workflows of the element in relation with other elements by means of interaction. Through this kind of information the designer can build models in a rapid way following user needs.

2.3.1 Authoring Toolkit

The Authoring Framework workspace is divided in three editors, one for each model (Fig. 2):

- User Model Builder. The term “User” here is referred to the beneficiaries of VAALID, i.e. elderly or people with disabilities people. This user editor defines the user profile including physical, sensory and cognitive abilities. This kind of information is collected during the design and testing phases when creating AAL services. Functions implicated in this builder are: creating a new User Model from scratch; importing or exporting an existing User Model, by exchanging profiles between the current Project and the Library (or Repository); and removing the User Model associated to the current Project. The same actions are available for the Behaviour of a User Model, which can be imported, removed, exported or associated to another User Model.
- Environment Model Builder. The Environment Model reproduces a standard real place with a series of properties. This editor allows developing the 3D simulation environment where users can be immersed, like in a real assisted world, and try new interaction modes and new (virtual) interaction devices. Pre-existing 3D models can be used to compose an Environment Model: common objects (including rooms, furniture or in general architectural elements), interaction devices (like sensors and actuators) and complex devices (a combination of the previous ones). Objects are characterised by their properties; interaction devices have also a behaviour. Complex devices have the same characteristics of an interaction device but are represented by a set of related sensors and actuators, targeted to a unique and

specific function, as a single composite device. An innovative feature is the possibility to browse among existing objects within the VAALID Library, allowing refining and reusing components, starting from a CAD program or a 3D animation tool which export objects as VRML or X3D files. To make the simulation more realistic the designer can make some minor modifications in dimensions and positions of the objects inside a scene. Similarly to the User Model, environments and objects are composed by properties and behaviour, and can be imported, exported, retrieved from the Library and edited through graphical metaphors.

- AAL Service Compositor. This tool is an editor for the creation of an AAL Service Model, which is mainly described as a workflow, providing links between user and objects of the scene. It essentially acts as a controller that processes information coming from sensors, triggered by explicit or implicit user actions, and consequently activates relevant actuators (i.e. security systems, lighting, heating/air conditioning), consistently with the service specifications.

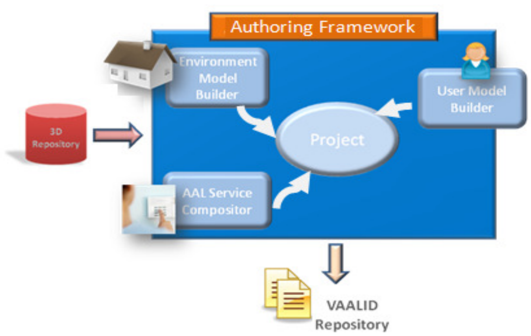

Figure 2: Authoring Framework scheme.

Three data layers are handled and exchanged for most of the modelled elements:

- *Representation*: graphical components that permit visualisation of each element and interaction with the designer.
- *Instance*: structure of classes that holds the actual element model and allows its management by Java modules.
- *File*: raw data that keep the element description when stored in a drive or the library.

Once created, every model can be exported to the VAALID Repository for reuse in further projects. This way the Authoring Framework gives the possibility to have an increasing amount of models to use in different simulations or execute many variants of the same simulation. Finally, the Project Editor integrates the three tools for editing models of user, environment and AAL service in a common framework in order to manage a single simulation.

2.3.2 Authoring Implementation Facts

According to the software architecture defined, each tool works using collaborative modules, managing and sharing pieces of software. The usage of Eclipse RCP (Rich Client Platform) is a step forward towards the implementation phase. This particular distribution includes the subset of components which are natively used to construct the own Eclipse framework. In this sense, client applications developed under Eclipse RCP share the same software infrastructure of Eclipse, taking profit from advanced built-in functionalities such as:

- Native visual elements of the Eclipse deployment platform.
- Perspective management, enabling different software views sharing the same data model.
- Plugin-based architecture, facilitating version control and modular development.
- Auto-update functionality that facilitates software maintenance.
- Integrated high-quality help files.

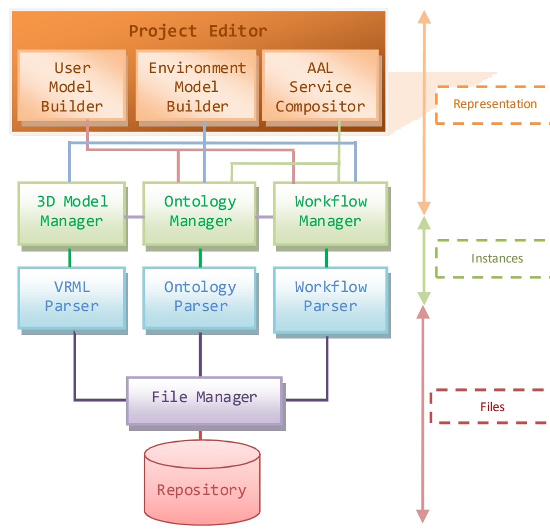

Figure 3: Authoring Framework modules diagram.

These capabilities enable certain advanced capabilities of the VAALID user interface concept, like the usage of perspectives to facilitate seamless transition between Authoring and Simulation Frameworks as well as to access content through different views and levels of detail (e.g. object browsers, flexible lists, 2D/3D floor plans), depending on user preferences and expertise. Individualisation of screen layout is also possible because RCP exploits the native potential of the same visual components of Eclipse.

Regarding the multi-developer condition of the VAALID software, the RCP architecture based on plugins allows modular independence among implementation teams, considering each plugin as an additional element of the final software framework. The auto-update feature will help in this modular approach, assisting in the adoption of updated plugin versions as soon as they are released. The integrated help infrastructure will make possible a low-effort extra support for VAALID designers.

As shown in Fig. 3, each editor in the Authoring Framework is composed of two main parts: Element Manager (Ontology Manager, Workflow Manager and 3D Model Manager) and Element Parsers (Ontology Parser, Workflow Parser and VRML Parser). The Element Manager performs the translation between instances and graphical representations, while keeping in memory the actual model of the elements. Particularly the Ontology Manager holds a more relevant role since it acts as a kind of overall controller, calling the other elements managers when required. The Element Parser is responsible for converting instances to files and vice versa, verifying that each element maintains a convenient format. To end with, it is remarkable that, according to the overall VAALID architecture, the Authoring Framework shares the same instance structure and memory with the Simulation Environment, in particular with the Simulation Control Panel. This assures seamless transition and permanent data consistency between both frameworks.

2.3.3 Viewing 2D/3D Spaces

One of the most innovative features of VAALID is the integration of 3D technologies in the Authoring Framework so as to dynamise and smooth the progress of designing and evaluating AAL services. In addition to the 3D view of the floor plan, the Authoring Framework provides also a 2D view in which it is possible to select objects and have a clearer idea of distances and orientation of all those elements that are present in the scene. Selections are synchronised so as the system automatically performs the changes in both views.

The Eclipse RCP platform provides some functionalities to facilitate 3D management. The use of perspectives and views permits immediate changing between 2D and 3D floorplans sharing the same data model imported from the original VRML file. The actions/views mechanisms enable direct manipulation of objects from the environment taking into account different selection sources (browser, flexible list, floorplans, workflow editor, history lists, etc.). The 3D Model Manager supports 3D rendering and navigation, allowing rotation, zoom and tilt within the user view, while detecting object collision.

2.4 Simulation Framework

Once the individual elements are defined, the process of creation of experimental AAL environments needs a testing and assessment phase. Thus, apart from a core set of technologies and software building components, there is a need [10] of appropriate facilities that offer the possibility of:

- Testing different technical solutions from the point of view of their overall usefulness to users.
- Providing a common environment for testing cooperative activities and virtual spaces.

Usually, testing ambient behaviour and interaction is only possible in real laboratories. The innovation of this approach is that it will be possible to test and assess AAL scenarios, products and services across all the development process in virtual environments, before experimenting in real contexts.

The models (service, user and environment), previously defined in the Authoring Framework, are put together and run in the Simulation Framework during the different stages of the development. Simulations provide feedback to developers about the accessibility, usability and user acceptance of the human-environment interaction. The Simulation Framework is composed of two main tools (Fig. 4): the Simulation Control Panel, which allows developers to configure and run the simulations, and the 3D engine or AAL Services interaction simulator, which is a renderer for the 3D scenes, based on Instant Reality system. Both of them communicate with a workflow engine, which is in charge of executing all the workflows related to a simulation.

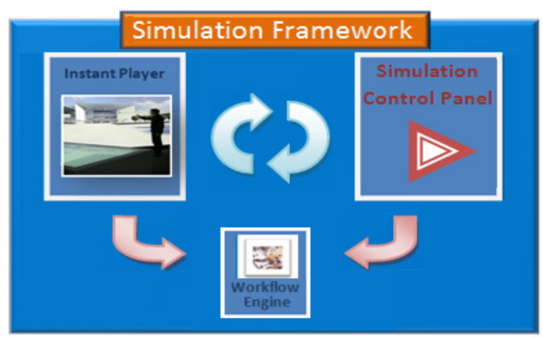

Figure 4: Simulation Framework scheme.

There are two types of simulation-validation tests that engineers can perform:

- A first type is done with virtual users. These are models of users defined within the Authoring Framework, and characterised by behaviour models. This phase of assessment is important for the integration of the different interaction modalities, since it allows definition and refinement of the behaviour model in any stage of the design process. Engineers can check constraints that state incompatible values for specific properties of the different elements defined in the AAL scenario.
- The second type involves real users in an immersive environment (3D virtual environment). Users will be allowed to experience real-time

interaction with an AAL environment using both virtual and tangible interaction devices. A virtual interaction device can be a sensor or an actuator represented in the 3D virtual environment; a tangible device (or simulation control) is physical equipment that enables interaction between the user and the virtual environment. The feedback from real users to designers will be critical in the process to meet their specific needs and requirements. At the moment, the project is exploring the feasibility of integrating several simulation controls to the platform, such as Nintendo Wii Remote, Intersense Head Tracking, LED-based Gloves, Visual Hand Control or Android Mobile Phone. These controls will be extensively assessed during the pilot tests, with the aim of finding the most adapted solution for each user.

The possibility of performing these assessment phases during the design process of AAL solutions, before building up real living labs, has key benefits such as saving of time and costs. In addition, users can participate in a controlled environment, since VR technologies assure safe and secure interaction. This does not mean that evaluation in a real living lab has to be avoided, but that any further interaction experiment will be enriched by the results obtained in the preliminary design process.

2.4.1 Study Case: Using an Android Mobile Phone

As stated before, VAALID aims at providing VR-founded tools that make easy the process of designing accessible solutions for ambient intelligence environments. The objective is to allow engineers to pre-validate innovative services with final users in a realistic setting using virtual scenarios, as a first filter before the actual validation in living labs. One important step in the investigation is the testing of different interaction devices in order to test the immersion feeling of users in joining the simulation.

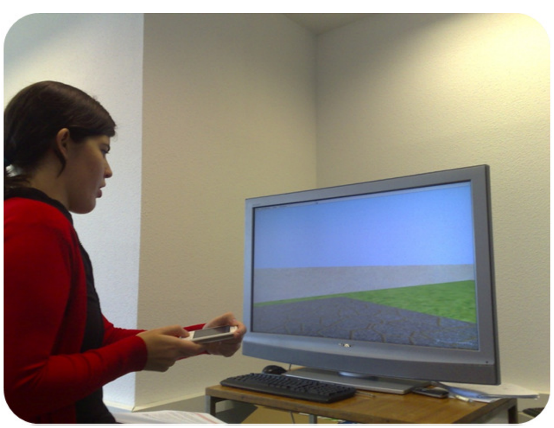

Figure 5: Testing VR using a smart phone.

Taking advantage of the flexibility of Instant Reality and the multimodal characteristics of the new generation of smart phones, a special setting was prepared to perform some technical and usability tests [11]. Several engineers were told to explore and interact with a 3D scene using an Android-based mobile device (i.e. HTC Magic smart phone), analysing the execution of some pre-defined tasks, such as moving around, finding objects or grab a book.

After considering different approaches, multimodal user interaction was defined using the handheld device as follows, focusing on haptic interfaces (Fig. 5):

- Device rotation (i.e. forwards, backwards, clockwise and counter-clockwise): performs 3D movements within the virtual environment (respectively: advance, retreat, turn right and turn left).
- Finger dragging over touchscreen: performs horizontal movements of the virtual pointer.
- Trackball rotation: performs vertical movements of the virtual pointer.
- Trackball click: sequentially picks up/releases a particular virtual object.
- Vibrator: provides vibration feedback to the user when the virtual pointer collides with the virtual object.

Considering the collected data, preliminary results show that users feel comfortable in using the device and defined the experience as realistic, although there are valuable suggestions to improve the interaction (e.g. allow sensitiveness calibration). From a technical point of view, this can be taken as a good starting point for future work with VR-based applications, although further research is required concerning its suitability for elderly users.

3 DISCUSSION AND CONCLUSION

Accessibility and usability concepts are currently considered within a limited range of ICT applications and services, mostly constraining its usage to research and development activities and presenting significant reservations when dealing with production and deployment phases. Although the seven principles of the universal design or Design for All [12] are well known and applicable to a wide variety of domains, business stakeholders are still highly reticent to apply them in practice. This lack of commitment with the elderly and disabled community, in particular when designing AAL solutions is mainly due to the high costs involved in the iterative design-development-testing procedure and the considerable time effort needed to meet user’s needs.

On the other hand, the adoption of VR technologies seems to confront with the purpose of designing services for people with disabilities, as few initiatives have been carried out in this field regarding accessibility requirements. Most of them deal with people with cognitive disabilities (dementia, autism, schizophrenia, Down's syndrome, etc.), proposing simple virtual worlds where users get immersed in order to learn some tasks, acquire some habits or recover some capabilities under a controlled scenario. Nevertheless, VR has been proven to offer significant advantages for persons with all kinds of disabilities. It can present virtual worlds where users can be trained or learn in a controlled environment, and then apply the skills acquired to a real context. VR technologies can be adapted to a wide range of users and needs, and at the same time, user's abilities and experience can be assessed in order to reach an optimal adaptation

The work proposed in this paper brings together all these issues into a technological approach that will have a beneficial impact for all the involved parts: The ICT designer will be able to evaluate the suitability of the proposed solutions with a significant reduction of the global design and development effort; business stakeholders will have a cost-effective solution and therefore new market opportunities, and finally, end-users will be provided with new services to improve their quality of life, and even better, they will be able to active and critically participate in the process of creation of these services.

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