A New Approach for Accessible Interaction within Smart Homes through Virtual Reality

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Abstract. This paper proposes an innovative Virtual-Reality-based interaction strategy integrated with a real domotics platform as a testbed to evaluate user experience of people with disabilities and their assistants. A living lab has been arranged to analyze and extract those applications with better acceptance for the users, making use of a multimodal approach to adapt the interaction mechanisms to their needs, skills and preferences. A preliminary testing phase validated the system in terms of performance, reliability and usability. A complete evaluation trial is about to be configured for assessing the final system with a wide range of target users.

Keywords: virtual reality, domotics, accessibility, living lab, smart homes.

1 Introduction

An increasing number of people currently experiment difficulties to perform daily activities, mainly because their close environments are not properly adapted to their needs, skills or preferences, especially in case of people with disabilities [1]. Pushed by social pressure, public investment and technological advances, plenty of accessible sites (including home, workplace or public spaces) are arising, in particular from an architectural point of view. Furthermore, progress in domotics provides improved adapted designs for home appliances, even though there are still important usability concerns to incorporate the latest technologies into everyday life [2].

Virtual Reality (VR) emerging technologies can offer significant opportunities to support user interaction in technological environments, helping to reduce the existing usability gaps [3]. The idea of integrating VR into domotic spaces as a channel to approach environment control to users implies the exploration of a very testable research area with promising perspectives for supporting independent living [4].

This paper aims at presenting the strategy followed in the Technical University of Madrid to establish a living lab for assessing user experience of people with disabilities in smart homes founded on two main technologies: VR and domotics. Further expectations of the research work include the validation of VR-based human-machine interaction in a variety of smart home applications with different profiles of users and interaction devices.

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2 Materials and Methods

The smart home infrastructure is located in the Laboratory for Domotic Usability Evaluations at the Telecommunication School of the Technical University of Madrid (UPM). The domotic installation is composed of several home appliances (lights, window blinds, doors, taps, heating) and environment sensors (presence, smoke, gas, flood, temperature), connected through an EIB gateway. An open architecture platform based on an OSGI middleware allows software-based environment control, while a set of web-based interfaces enable secure and personalized local/remote access to the domotic services [5].

A virtual environment has been developed trying to replicate the real appearance of the laboratory, using Multigen Creator[1] for 3D design and EON Studio[2] for interactivity. Users may interact with the system through a convenient combination of different displays and devices:

- 6 m^2 Stewart retro-projection screen[3] for stereoscopic glasses
- Trivisio AR-vision-3D[4] stereoscopic binocular display
- 5DT HMD 800 head-mounted display[5]
- 5DT Data Glove 5 for detecting finger motion[5]
- Intersense InterTrax 2 tracking system with 3-DOF[6]
- Stereo sound system
- Different models of tactile screens, mice and keyboards

The implementation of the VR-based solution went through the following phases: 1) graphical design of the virtual elements for a realistic 3D representation; 2) compilation of individual components into the simulated lab; 3) integration and configuration of multimodal interaction devices (visual, tactile, acoustic and haptic); 4) incorporation of animation and interactivity to the virtual scene; 5) development

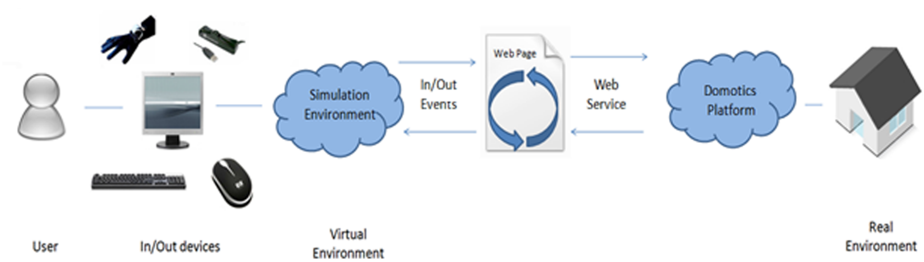

Fig. 1. System architecture representation

[1] http://www.presagis.com
[2] http://www.eonreality.com
[3] http://www.stewartfilmscreen.com
[4] http://www.trivisio.com
[5] http://www.5dt.com
[6] http://www.isense.com

of a Web-Service-based bi-directional communication interface between the virtual and real environments; and 6) deployment of VR solution over most web browsers (taking advantage of EON Reality's Web plug-in).

The Design For All principles [6] have been considered all along the design and implementation process, taking into account concepts such as usability, adaptability, multimodality or standards-compliance. The resulting architecture of the system is represented in Fig. 1.

3 Design of the Virtual Environment

One of the key factors that support accessibility is the provision of multimodal user interfaces. Multimodality, as the possibility of using in parallel more than one interaction modes for communication between user and system, has been implemented in four modes. On one hand, visual and acoustic modalities are used for system output. Inputs to the system are in contrast achieved through tactile and haptic methods. A more detailed description is included below:

- **Visual:** The 3D representation of the virtual lab and its components give the main feedback to the user: virtual doors have been provided with (open/close) motion, lights change their color to differentiate between on/off status (conveniently updating light conditions in the whole virtual environment), water pours from the tap when open, etc. Every interaction option is indicated with a help tool, both textual and graphical, to facilitate user's navigation along the scene. Moreover, the user has also the possibility to visualize the real living lab at any time through a web camera. Several PC screens, VR displays and HMDs allow personalized visualization scenarios.
- **Acoustic:** In addition to the visual help tools, acoustic messages guide the user in the navigation and interaction with the scene: for instance, when the user points an interactive device such as the door, a voice message informs about the different interaction possibilities (e.g. open/close). Virtual elements are also complemented with acoustic signs to increase the user's immersion feeling, like the sound of window blinds raising or water pouring from the tap. This modality is implemented through a stereo sound system, either integrated in the environment or through personal headphones.
- **Tactile and haptic:** These two modalities allow the user to navigate in the virtual scene and control its elements. Navigation provides the user with a feeling of presence into the virtual environment, as s/he can move all over the scene (forward, backward and around), collide with the virtual objects, observe in any direction, make zoom and even change the point of view. The different interactive devices of the scene (e.g. lights, doors, webcam) can be controlled too, changing their status through a combination of these modalities. Complete tactile interaction is possible by pressing keyboard buttons, moving and clicking the mouse or touching the tactile screen. Haptic communication is implemented by detecting commands from hand-based gesture recognition (using the VR glove) as well as by aligning user perspective along with head or arm real-time orientation (through the 3-DOF motion tracker).

Furthermore, the system has been designed according to various guidelines and recommendations in order to make it accessible and user-adapted [7][8]:

- Users are enabled to perform tasks effectively using only one input device, such as mouse, keyboard, tactile screen or data glove.
- The virtual environment provides object descriptions that are meaningful to users (when interactivity is enabled). Visual objects that are primarily decorative and contain little or no information need not be described.
- Users can easily activate a graphical menu to personalize different interaction features (e.g. acoustic signals)
- Users are provided with both acoustic and visual feedback when they interact with the elements in the scene (including alerts).
- Users are allowed to change the point of view and make zoom in the scene so as to find the most comfortable perspective.
- Every interaction has been implemented with at least two modalities: e.g. users can turn on/off the light either tactually (tactile screen, keyboard, mouse) or haptically (data glove), whereas feedback is obtained both graphically (screen, VR display) and acoustically (stereo system, headphones). Although voice recognition is still not supported, it is being considered as a significant improvement for the system.
- Immersiveness can be adapted according to user preferences, from selecting specific visualization devices (e.g. HMD instead of PC screen) to simulating the own user's hand in the virtual scene. The inclusion of a virtual avatar is under consideration for further research.
- Users can combine the different interaction devices and modalities as they wish, to achieve the most usable solution for them. At present, most VR interfacing devices are wired, presenting tough usability concerns. Emerging wireless gadgets are to provide a relevant step forward in this sense.

4 Results

The proposed solution has resulted in a running living lab for testing VR applications in the smart home domain, especially devoted for people with disabilities. This approach permits that users move around and interact with home appliances in a virtual environment, allowing them to check and change online the status of real devices directly through the 3D virtual elements (Fig. 2). To keep consistency between both real and virtual environments, status and orders for each device are shared by means of continuous feedback through an Internet connection and a typical web browser. Because of the collection of displays and interactive devices included, users may play around with different interaction modalities and degrees of immersion. Also some visual and acoustic guidance and help tools have been provided, to facilitate navigation within the interface and make it more intuitive.

In addition, by adjusting a number of configuration elements on the user interface, the same interactive application may be validated for different settings and user profiles. In case the virtual environment is disconnected from the real lab, the application can be used by elderly or cognitive disabled to learn how to manage domotic installations in a non-threatening environment, while those with physical impairments may

Fig. 2. Views of the UPM living lab: real picture (left) vs. virtual representation (right)

exploit the system to find the most convenient combination of modalities and interaction devices. By keeping both labs interconnected, confident users can go one step further and take the application directly as a ubiquitous remote control of the smart home, enabling them to check, both indoors and outdoors, the status of any home alarm or change in advance the temperature of the heating system. Moreover, carers, relatives or informal assistants are able to monitor in a non-intrusive way the real environment of any person requiring external supervision.

A preliminary evaluation phase has been carried out to validate the system in terms of performance, reliability and usability. 25 volunteers were able to assess combinations of the different displays and interaction mechanisms, both in simulated and real running modes. The results have been satisfying in terms of system usability, supporting the interest in VR technologies applied to smart home interaction. At present a complete validation procedure is being arranged, considering several user profiles from people with disabilities, professional assistants and informal carers.

5 Discussion and Conclusion

VR technologies are in general adaptable to a wide range of individual requirements. Particularly, the multimodal approach inherent to VR and the low-effort interaction techniques followed can make VR-based interfaces especially valuable for users with disabilities or special needs. Conjunction of these facts may enhance the variety of accessible solutions for addressing the specific impairments and preferences of each person, especially in terms of interaction limitations. This involves not only physical, but also cognitive disabilities:

– People with hearing impairments are perfectly able to use this system, since acoustic output is not essential for correct operation: all acoustic signals have their equivalent visual feedback.
– In contrast, acoustic feedback reinforces the capability of a user with low vision to navigate and interact with the environment.

- Someone with limited mobility can benefit from both haptic and tactile modalities to control domotics in an error-tolerant environment, without requiring excessive effort or accuracy.
- Tactile modality combined with acoustic and visual guidance may be useful for children with attention disorders [9].
- Elderly and people with certain phobias can experiment with new technologies in virtual environments so as to learn, get used to them and overcome their fears [10]: the system offers the option of interacting with just the virtual world, without real connection to the domotic platform, consequently avoiding any risk related to device operation.

In summary, this paper has presented an innovative approach that looks for accessible user interaction with a smart home control platform through VR. The current research work aims at giving answer to a number of open issues such as:

- The adequacy of VR for enhancing user experience for people with disabilities.
- The chances of VR as widespread usable human-computer interaction method.
- The convenience of VR for a daily handling of domotic environments.

From the preliminary results of this work, we can conclude that VR shows promising possibilities for providing disabled people with more adapted access to domotic-related applications, mainly due to the capability of integrating different interaction devices.

In this sense, the addition of other modalities, like natural language voice recognition or augmented reality, or new interfacing devices coming from the emerging generation of intuitive wireless gadgets for entertainment or telecommunication, might be the starting point for definitely spreading VR technologies while fostering their key role in improving accessibility for people with special needs.

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