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Abstract (for dissemination)	The familiarization of the user with the novel interface BCI requires a training period to control it properly. The Virtual Reality together with the Scenario Modelling tool represent an added value during the familiarization stage. In fact, this virtual world provides a representation of the end-users home that allows the user to navigate freely through the different virtual rooms and interact with the smart home devices. The XML-based language HomeML is the responsible for providing the configuration to the Scenario Modelling Tool in order to build up the representation of the home. Finally, the virtual world of BrainAble also provides a direct synchronization between both virtual and real worlds. Indeed, the Virtual-to-Physical gateways feature of the system enables that the actions taking place in the virtual representation also have an impact on the real world.
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1 Introduction

BrainAble, an EU Seventh Framework Program (FP7) financed project, is to research, design, implement and validate an ICT-based Human Computer Interface (HCI) composed of BNCI (Brain Neural Computer Interface) sensors interacting with affective computing and virtual environments. This combination will significantly improve the quality of life of disabled people by overcoming the two main limitations they suffer - exclusion from home and social activities - by providing inner functional independence for daily life activities and autonomy (HCI connected to accessible and interoperable home and urban automation) and outer social inclusion (HCI connected to advanced and adapted social networks services).

In terms of HCI, BrainAble will improve both direct and indirect interaction with computers. Direct control will be upgraded by creating tools that allow people to control those inner and outer environments using a Hybrid Brain Computer Interface system. This hybrid approach is called BNCI and is the application of BCIs in conjunction with other physiological inputs as is the case of Electro Oculography (EOG), Electromyography (EMG), or Heart Rate). Furthermore, BNCI information will be used for indirect interaction, such as changing interface or overall system parameters based on measures of boredom, confusion, frustration, or information overload. These self-adaptive tools will increase effective bandwidth because users will be able to use a plurality of signals to affect control, and also because adaptation will reduce errors and help provide the user with the desired control. In BrainAble, HCI will be complemented by an intelligent user interface based on Virtual Reality using avatars and scenarios that will help disabled people to move around as would be the case of wheelchair control, interact with all sort of devices, create self-expression assets using music, pictures and text, communicate online and offline with other people, play games to counteract cognitive decline, and get trained in new functionalities and tasks.

The Virtual Reality in the scope of BrainAble, is intended to be a virtual representation of end-user's home, by means of the Scenario Modelling Tool (SMT), with the final goal of providing the ability of navigating for those who have mobility impairments. In fact, the SMT will also allow to interact with the smart home appliances. For this purpose, the XML-based language HomeML is the format language designed to describe a virtual environment to have such conceptual representation. This language includes the description of size and location of the elements in the home, the passive elements, but also enumerates the different active elements with which the user can interact, the so-called active elements. Finally, the VirtualReality of BrainAble includes the Virtual-To-Physical gateways functionality, which ensures a perfect synchronization between both virtual and physical worlds. That is, an action that takes place in the real world has an effect on both virtual and real world (e.g. Turn on a light).

This document describes all these functionalities and it is structured as follows. In Section 2, a short description of the benefits of VR in the context of BrainAble. Section 3 presents the designed architecture along with the designed data flow between VR and AmIBlock module. In Section 4, a description of the *Scenario Modelling Tool* is included aimed at creating a virtual environment which corresponds to a representation of the user's home. Eventually, Section 5 describes the conclusions of the document.

2 Virtual Reality and healthcare

Recently standard rehabilitation has been augmented with several technological advances such as virtual reality (VR) (O'Dell et al., 2009). The use of virtual reality systems allows for interaction, provides users with feedback regarding their success while also allowing for the realization of a wide range of tasks including activities that might otherwise pose a risk to the patient. VR also allows otherwise repetitive tasks to become engaging and challenging activities and have the advantage that they easily transfer from clinic based training to at home applications for telerehabilitation, creating a continuum of diagnostics and training possibilities. The strength VR approaches is that they facilitate interfacing to a range of peripheral devices.

In recent years, clinical studies have begun to demonstrate the effectiveness of Virtual Reality (VR) as an intervention tool for a variety of neurological conditions (e.g., Jack et al., 2001; Schultheis & Rizzo, 2001; Weiss, Naveh, & Katz, 2003). There remains, however, a number of important issues that must be addressed in order to determine how widely VR-based intervention could be applied, and the ways in which specific patient populations can benefit from its unique attributes.

The rationale for the use of VR in rehabilitation is based on a number of unique attributes bound to this technology (Rizzo, 2002). These attributes include the opportunity for experiential and active learning that encourages and motivates the participants (Mantovani et al., 2003). In fact, previous studies have suggested that there is a strong correlation between motivation and the sense of presence produced by VR Environments (Christiane B. Lourenço, Liza Azeff et al., 2008). Moreover, VR permits to the therapists to objectively measure behaviour in challenging but safe environments, while maintaining strict experimental control over stimulus delivery and measurement (Rizzo et al., 2002). VR also gives therapists the ability to individualize treatment needs, while providing increased standardization of assessment and retraining protocols.

In the context of BrainAble, the Virtual environments provide the opportunity for learning trials and offer the capacity to gradually increase the complexity of tasks to be committed with the novel interface, the BCI. Indeed, the usage of BCI needs a training stage in order to get the end-user ready for have a full-control of the features of the system.

3 BrainAble technical solution

BrainAble is designed with a centralized modular architecture around the AmIBlock.
Figure 1. shows a high level block diagram of the different modules together with their interactions. The general vision of BrainAble is composed of 5 modules: *BCI Module, VR Module, Weather Sensors, UCH Module, and AmIBlock*. All the communication paths in BrainAble have to pass through the AmI Module, which keeps track of all the happenings that take place in the system (e.g. user interaction, changes in the environment) in order to give a proactive response to each situation.

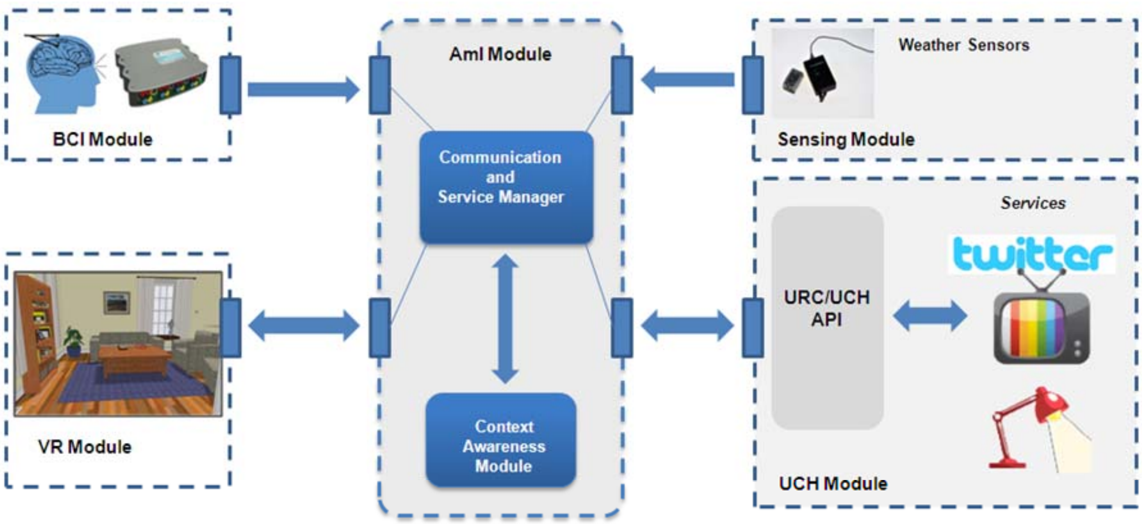

Figure 1. BrainAble centralized architecture consisting of 5 modules: BCI Module, VR Module, *Weather Sensors, UCH Module and AmI Module*

The *BCIModule* contains the BCI processing logic and hardware, and GUI to transform the user's brain signals into an action or command to be executed. The BCI actions are accessed via a hierarchical menu that is visually presented to the user. For example, the user must select using the BCI, "AMIDevices" then "TVChannelUp" in order to execute the command that increases the channel on the television. The platform has been implemented with two BCI techniques, the P300 Matrix and the Hex-o-Select which allows the user to select the technique with which he feels more comfortable.

In order to gather useful contextual information, the *Sensing Module* will provide access to environmental and physiological sensors. Currently temperature, luminosity and humidity of the room are being captured, together with presence.

The *Universal Control Hub (UCH) Module* is a middleware that provides a uniform and consistent API to all devices and services via a HTTP protocol gateway. In this manner, the communication with the different services of Brainable, are accessed via a unique technology them enhancing the system modularity. Devices and services can be attached to the UCH and their status and control are available via the gateway.

BrainAble provides a virtually interactive environment through the *VR Module* for training a new user in the usage of the novel BCI interface. Virtual Reality provides three different applications:

- *Customisation Suite*: The user is represented by a virtual avatar that can be customised in order to get a character representing the user. The Customisation Suite offers the possibility to the user of creating and changing the appearance of the avatar that will represent him in the virtual world.

- *Virtual Home:* A model of the user's home that represents it virtually allows the user to navigate in his home and interact with the SmartHome devices. The Virtual-To-Physical gateway functionality will provide a synchronisation between these two worlds.

- *Virtual Community:* The user will be transported to a virtual community in which he/she will be able to interact (e.g. chat, play games) with other users of BrainAble. These virtual environment is devoted to take advantage of the

All commands issued by the BCI pass through the *AmIBlock*. By continuous use of the system, the AmI Module is able to learn the user's personal habits by a Bayesian based algorithm described later in the section. When a similar context arises, similar to the ones previously seen, the AmI Module is able to provide back to the BCI a list of probabilities of the most likely actions. Using this list the BCI is able to provide through an adaptive shortcut area direct access to the action, saving the user time spent by navigating through the hierarchical menu.

3.1 Communication AmI-VR

The communication between the AmIBlock and the Virtual Reality is necessary for ensuring the proper flow of information. For this reason, a protocol was established for providing the user selections to the VR through the AmIBlock, which centralises all the information of the context (e.g. user interaction, changes in the environment). The three figures below describe the interactions between the modules in three cases: initialisation of the system, VR User command and VR Triggers

The following figure illustrates the interactions between the modules during the initialisation stage of the system in which the AmIBlock exchanges information with the VR for constructing the virtual representation of the home.

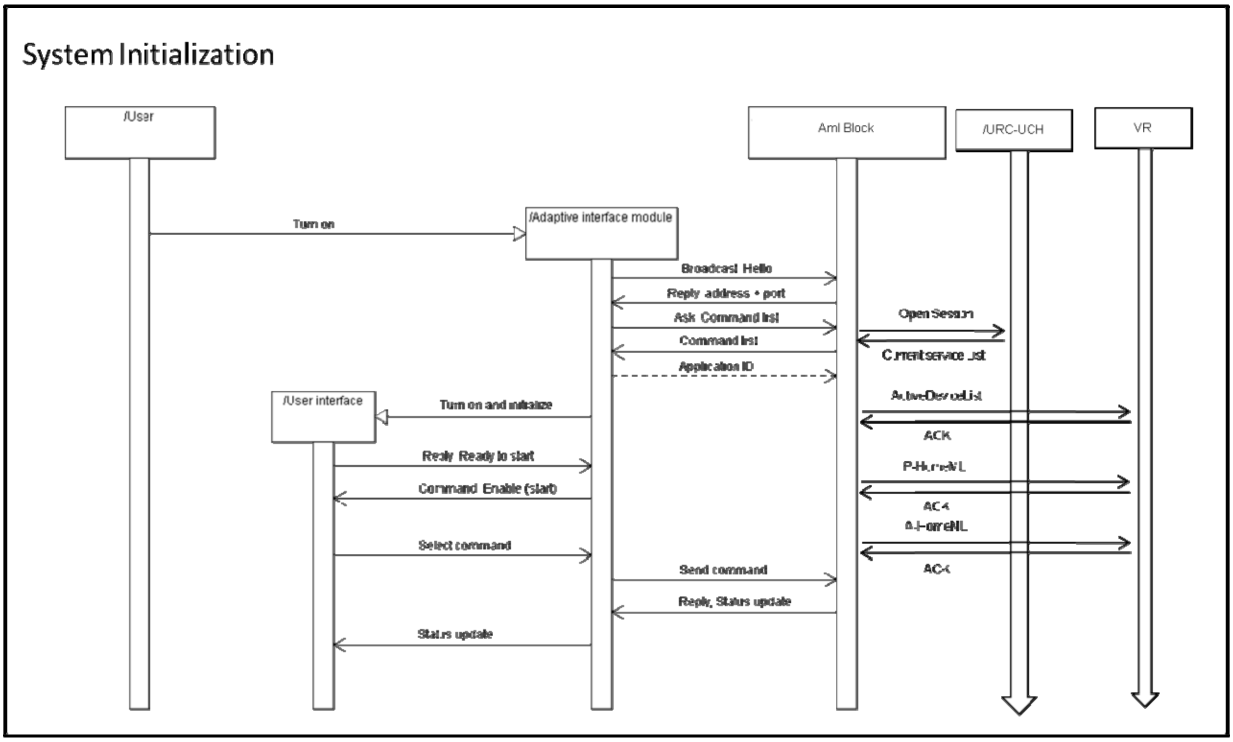

Figure 2. BrainAble VR initialisation

SystemInitialisation refers to the initialisation of the system where the AmIBlock sends the A-HomeML and the P-HomeML (See section 4.1 for further details)

1. The user power on the system
2. The AmIBlock sends the P-HomeML to the VR and waits for the acknowledge of the command, which is sent by the VR.
3. The AmIBlock sends the A-HomeML to the VR and waits for the acknowledge of the command, which is sent by the VR.
4. The VR system is initialised

VRCommand refers to a command sent by the BCI interface, specifically the AIM, to the Virtual Reality through the AmIBlock. The following figure is divided into:

Navigation command which is not relayed to the URC-UCH (i.e. real devices) since it is related to the avatar navigation in the virtual world

1. The user sends a command to the AmIBlock with the AIM.
2. The command is registered in the Context-Awareness module, as user interaction information.
3. The command is forwarded to the VR
4. The VR executes this command and displays the new status of the VR to the user

DeviceControl is related to a command that if forwarded to both the VR (i.e. virtual devices) and UCH (i.e. real devices) in order to provide the *Virtual-To-Physical Gateways* functionality. See section 3.2 for further details.

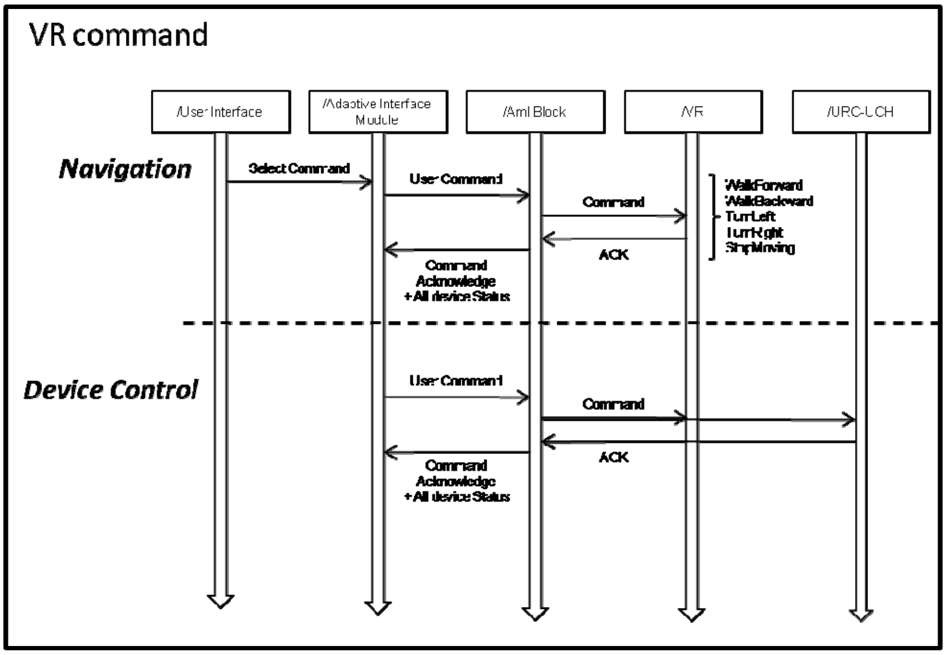

Figure 3. VR User command and acknowledge

VRTriggers in which the virtual avatar gets to a closer position of an interactive device and a notification is sent to the User Interface indicating that an interaction with the device is possible due to the proximity of the avatar (e.g Turn ON the TV).

1. The virtual avatar gets closer to a interactive virtual smarthome device
2. The command is registered in the Context-Awareness module, as user interaction information.
3. The command is forwarded to the UI

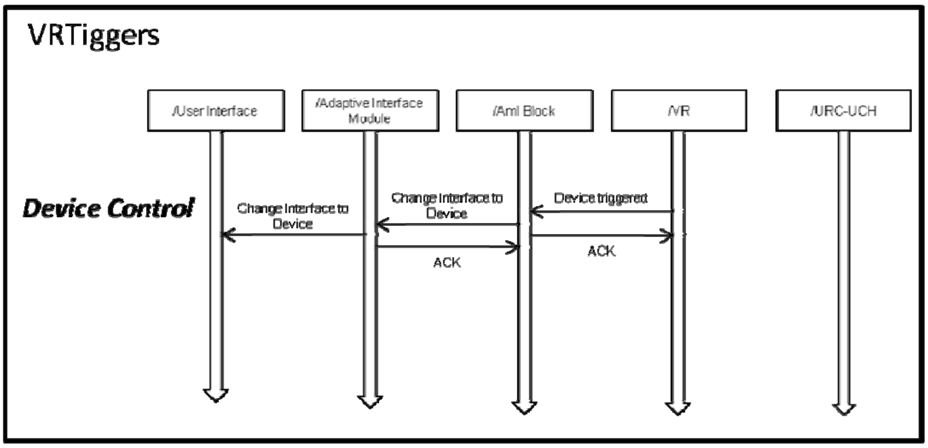

Figure 4. VR Triggers and acknowledge

3.2 Virtual-To-Physical Gateways

The Virtual-To-Physical Gateway corresponds to the ability of BrainAble to allow the user to control SmartHome services or other appliances via the virtual model of his/her home and, from the other side, visualize the changes occurring in the real world in the virtual environment. In other words, the inclusion of a virtual reality environment based on a friendly, intuitive and personalized user interface serves as a gateway to translate user commands into physical actions and vice versa. It is the integration of the visual environment and the AmI system containing the connected home devices, that enable the user to operate the basic device functions through the visual model of these devices depicted within the visual environment. These types of actions are therefore determined by the architecture of the AmI system and the physical infrastructure or home model.

The following figure depicts the interaction taking place between all the modules from the BrainAble architecture. Multiple interactions were included in the prototype, which depicts the interaction between the three actors: VR, UCH and AmIBlock.

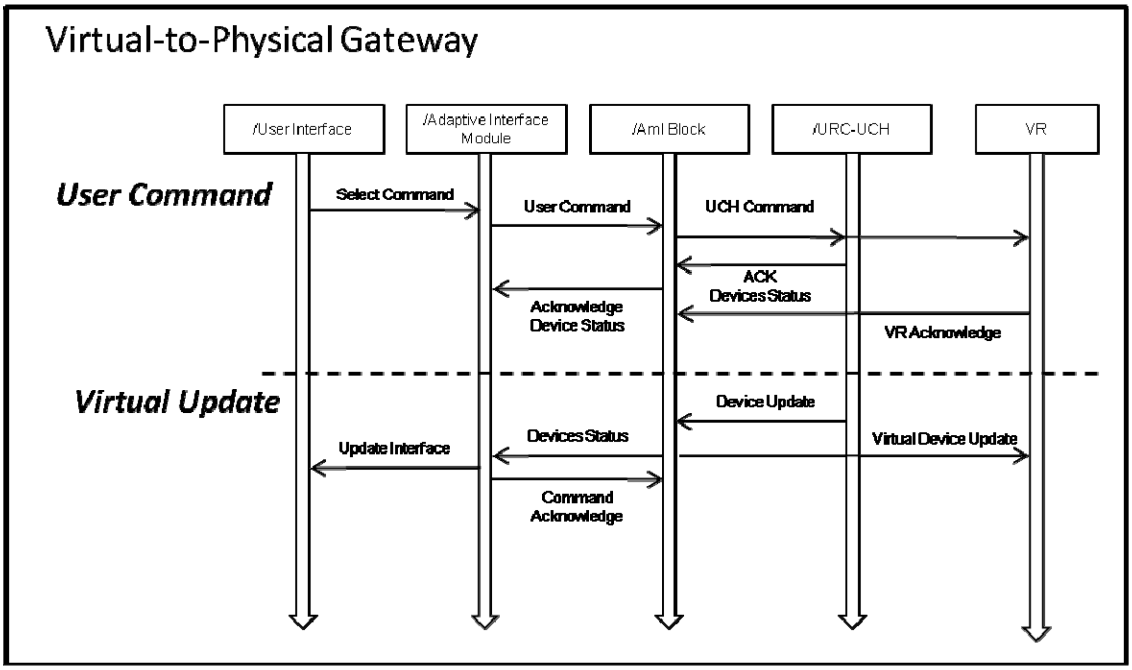

Figure 5. Virtual-To-Physical feature. Module interaction

The paragraphs below describe the two most illustrative interactions which are shown in Figure 5. This interaction between these modules can help to understand the effects of one action in the real world in the virtual, and viceversa.

UserCommand refers to a command selected by the user via the BCI interface which relayed to the real and virtual worlds.

1. The user selects a command in the user interface
2. The command is lately relayed by the Adaptive Interface Module to AmIBlock
3. Ambient Intelligent block registers the command into the ContextAwareness module as information from the user interaction
4. AmIBlock sends forward the command to both the devices via the URC/UCH and to the virtual home, via the VR

VirtualUpdate corresponds to the treatment of a change that takes places in the virtual world which is captured by the AmIBlock and synchronised with VR.

1. A change takes place in a device (URC-UCH)
2. A notification is sent to the AmIBlock which registers the information in the Ambient Intelligence engine
3. AmIBlock relays this information to the AIM which, in turn, displays this new status of the device, if necessary, in the interface
4. AmIBlock sends the new status of the device to the VR and reflects that change into the virtual home

4 Scenario Modelling Tool

4.1 Description of Virtual Reality environment: HomeML

An important feature of the BrainAble system is its ability to be easily configurable. This permits a faster integration and expansion of the system by the development of the necessary APIs with "plug and play" capabilities based on the Target Adapter concept provided by the UCH.

The Virtual Reality of BrainAble is a representation of the end-user home and, therefore, the VR needs to be a representation aligned to the real home of the user and be adaptable to the changes it may occur such as adding, moving or removing home appliances. Additionally, the system needs to take into account those appliances which are considered active, that is, SmartHome services. The changes in these services need to be reflected in both real and virtual world. The tool used for such purpose is the XML-based language HomeML which is able to improve the scalability and adaptability of the system, since further integration of new devices into the virtual environment will be handled through a normalized and documented procedure.

There are basically two different functionalities related to the representation of the user's home in a virtual reality: Passive Elements HomeML (P-HomeML) and Active Elements HomeML (A-HomeML). Both representations are described in XML as we will see in next paragraphs.

The **P-HomeML** is intended to describe the passive elements of the room, that is, all those elements that are interactive such as rooms, windows, doors but also elements of the furniture like chairs or tables.

The following table depicts an example of the application of the P-HomeML in which three rooms are defined (living room, kitchen and bedroom) along with the dimensions and the passive elements. For example, there is a sofa in the living room.

```
<passiveHouse>
   <name>GregsHome</name>
   <owner>Greg</owner>
   <roomlist>
      <room name="living room" length="500" width="400" VRasset="indoors"
color="#FFFFFF">
         <door to="kitchen" wall="north" offset="200"/>
         <door to="main entrance" wall="south" offset="200"/>
         <door to="my room" wall="east" offset="200"/>
         <window wall="west" offset="200" blinds="yes"/>
         <object active="no" type="sofa" color="#FF0000">
            <From x="400" y="0"/>
            <To x="370" y="50"/>
         </object>
         <object active="no" type="table" color="#643200">
            <From x="10" y="0"/>
            <To x="30" y="0"/>
         </object>
      </room>
      <room name="kitchen" length="300" width="300" VRasset="indoors" color="#FFFF00">
         <door to="living room" wall="south" offset="200"/>
         <object active="no" type="table" color="#643200">
            <From x="200" y="270"/>
            <To x="250" y="300"/>
         </object>
      </room>
      <room name="bedroom" length="400" width="400" VRasset="indoors" color="#00FFFF">
         <door to="living room" wall="west" offset="200"/>
         <object active="no" type="bed">
            <From x="0" y="0"/>
            <To x="200" y="100"/>
         </object>
         <object active="no" type="chair" color="#643200">
            <From x="0" y="200"/>
```

```
            <To x="50" y="250"/>
         </object>
         <object active="no" type="chair" color="#643200">
            <From x="370" y="370"/>
            <To x="400" y="400"/>
         </object>
      </room>
      <room name="garden" length="400" width="400" VRasset="outdoors" color="#00FF00">
         <window wall="east" offset="200"/>
      </room>
   </roomlist>
</passiveHouse>
```

Table 1. P-HomeML (Floor Description HomeML)

The **A-HomeML** includes the definition of those appliances or devices with which the user can interact. Indeed, the interactive services are the ones that the prototype includes and fulfill the functionality of *Virtual-To-Physical Gateways*

The following table depicts two active elements, a light and a TV, that are present in the living room together with their position and size. The identifier of every device will be used for matching both real and virtual device.

```
<activeHouse>
   <name>GregsHome</name>
   <owner>Greg</owner>
   <roomlist>
      <room name="living room">
         <object name="Light" type="light" id="DD_LR_002">
            <state>true</state>
            <trigger>false</trigger>
            <objectArea>
               <From x="10" y="0"/>
               <To x="30" y="0"/>
            </objectArea>
            <triggerArea>
               <From x="0" y="0"/>
               <To x="40" y="10"/>
            </triggerArea>
         </object>
         <object class="TVBean" name="TV" type="table" id="DD_LR_001">
            <state>true</state>
            <trigger>false</trigger>
            <objectArea>
               <From x="370" y="290"/>
               <To x="400" y="320"/>
            </objectArea>
            <triggerArea>
               <From x="360" y="280"/>
               <To x="400" y="330"/>
            </triggerArea>
            <channel min="0" max="20">6</channel>
            <volume min="0" max="20">12</volume>
         </object>
      </room>
   </roomlist>
</activeHouse>
```

Table 2. A-HomeML (Interactive Services HomeML)

These capabilities will supply a seamless and adaptive integration gateway for physical devices into the virtual environment, providing simplified procedures to model and virtually represent different sets of sensors and electronic components. The virtual scenario and the AmI system components must coincide with the physical description of the user’s home environment.

4.2 Technical solution for Scenario Modelling Tool

The Scenario Modelling tool was developed as a module of the Virtual Reality and it is based on the 3D engine Unity3D. In order to configure the virtual home, the VR receives the P-HomeML and A-HomeML descriptions from the AmlBlock. Subsequently, the messages are deserialised and interpreted to create a 3D representation of the user's house. Additionally for the objects described in the A-HomeML, it is created the connection to the real world, that is, those objects that have a correspondence in the real environment.

Deserialization of A-HomeML and P-HomeML

As described in 4.1, P-HomeML and A-HomeML are XML descriptions. The Scenario modelling tool implements a deserialisation module based on .NET technology, using a tool that transfers the XML description into the program memory. From this description, the engine creates an object in memory that contains all the information regarding the virtual world accessible any time from the code without needing to revisit the XML again.

Mapping of house description to 3D world

The real world is mapped to the 3D world based on the description of the rooms and the passive objects (P-HomeML) and the active objects (A-HomeML) in the room. Each object of the real world has a generic 3D representation, meaning that they are not reproductions of the elements present in the real house but reproductions.

In the 3D engine, it was created a library of objects that can be part of the house (e.g. door, window, sofa, table, lamp, bed, etc) and the building blocks with the respective textures (walls, ceiling, floor). This set of objects will be used to make such representation of the user's home.

The floor plan is built dynamically constructed based on the orientation of the spaces and the specified sizes of the (P-HomeML). In a second stage, the passive and active objects are instantiated and positioned in the room.

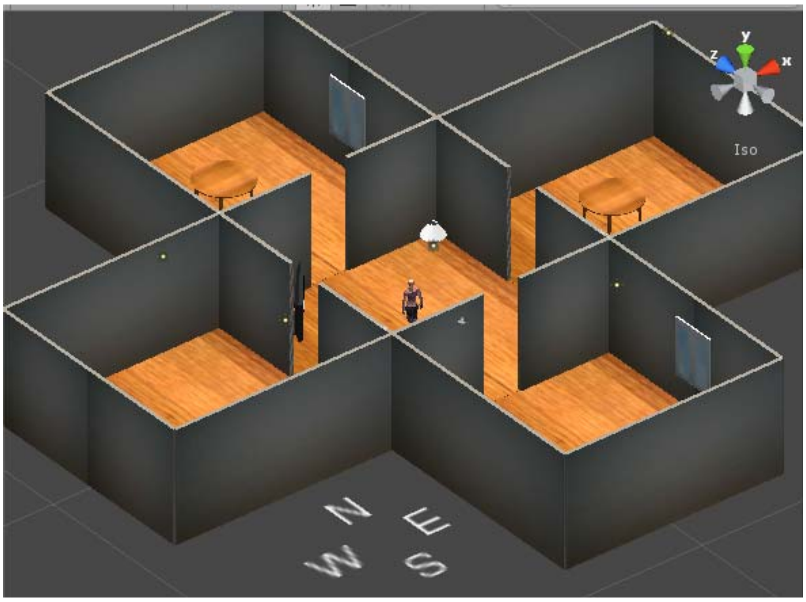

Figure 6. Floor plan created dynamically from the P-HomeML and A-HomeML descriptions.

Virtual to Physical gateway

For the active objects in the 3D world, it is included an additional behaviour that allows them to be connected to the real house. Indeed, each active object is capable of receiving messages, through the network connection that exist between the VR and the AmlBlock. These messages are interpreted differently by each of the objects (TV, door, light, etc). For example, a light in the VR world must represent the state of the real world (on, off), this is represented in the virtual world by modifying the illumination properties of the virtual world. Another object like the door must change their position in the virtual world to represent the state (open, close).

From another perspective, the VR can send messages to the AmI when the virtual user is approaching to an active device, the VR triggers. The message is send as a trigger, indicating that the avatar of the user is close to an active device. Each active object has a collision area in the 3D world (defined by a sphere). When the character enters the collision area of the active device, the event is captured and is sent as a trigger command to the AmlBlock that treats such event.

Figure 7. User avatar in the activation area of an active object

5 Conclusions

The use of Virtual Reality in BrainAble, allowing interaction, provides a powerful tool for improving the cognitive stimulation of patients. In the scope of BrainAble, the familiarization of the user with the novel interface BCI requires a training period to control it properly. The Virtual Reality together with the Scenario Modelling tool will be used mainly during the familiarization stage. The virtual world provided corresponds to a representation of the end-users home that allows to navigate freely through the different virtual rooms and to interact with the smart home devices.

The XML-based language HomeML is the responsible for providing the configuration to the Scenario Modelling Tool in order to build up the representation of the home.
Finally, the virtual world of BrainAble also provides a direct synchronization between both virtual and real worlds. Indeed, the Virtual-to-Physical gateways feature of the system enables that the actions taking place in the virtual representation also have an impact on the real world.

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