VR Serious Games for Neuro-cognitive Rehabilitation of Patients with Severe Memory Loss

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Abstract. Retrograde amnesia is a severe memory loss dramatically affecting patient's quality of life. Traumatic brain injuries, strokes, degenerative processes or metabolic disorders are the main causes. At present, rehabilitation tries to recover patients' memory by means of neuro-cognitive exercises guided by a physiotherapist. Unfortunately, the adherence to these rehabilitation exercises drops when patients are discharged from hospital. Furthermore, conventional rehabilitation is usually performed using standard exercises, which are not customized to each patient. The reproducibility of real environments and situations is a crucial feature to guarantee the efficacy of neuro-rehabilitation and it is defined as ecological validity. Ecological validity is important for making the exercises useful to re-learn specific information and for performing daily activities with the lowest effort. Nowadays, the traditional rehabilitation for retrograde amnesia is based on a set of pictures shown to the patient to remember or learn familiar environments, such as his/her home. This approach is very limiting because the patient can see few points of view of the home without learning and memorizing how to move and get into a specific room. Therefore, the traditional approach has a low ecological validity. The advent of innovative technology, like 3D scanners and virtual reality, permit the design of innovative solutions that virtually replicate patient's home. This research work presents a novel procedure to design serious games for neuro-cognitive rehabilitation for patient with retrograde amnesia. The proposed procedure exploits low-cost and free technologies; in particular, the Occipital Structure sensor has been chosen as 3D scanner to acquire the 3D indoor environments, which are used inside Unity to develop the game logic of the serious games. The HTC Vive Pro head mounted display has been used to interact with the serious games in an immersive way. The designed procedure makes available a set of Unity scripts to develop the serious game for new patients by changing only the 3D environment (i.e., patient's house). The procedure has been tested by creating three different serious games and the total time to create them can be approximated to a working day. The obtained results have been shown to medical personnel who have evaluated the proposed approach with a high ecological validity and decided to plan future medical tests by involving patients.

Keywords: retrograde amnesia, rehabilitation, ecological validity, Occipital Structure sensor, Blender, Unity, virtual reality.

DOI: https://doi.org/10.14733/cadaps.2021.1233-1246

1 INTRODUCTION

Retrograde amnesia prevents a person from remembering events or information acquired before a serious event involving the brain occurred. It is mainly caused by traumatic brain injuries [7], strokes, degenerative processes or metabolic disorders. For this kind of memory loss, the patient has complete lucidity for everything that happens after the brain trauma and has no difficulty memorizing new information [6]. In order to recover the lost memory, patients take part to a neuro-cognitive rehabilitation process guided by physiotherapists in a rehabilitation center. However, the adherence to rehabilitation exercises drops when patients go back home. The challenge we are facing is to improve neuro-rehabilitation effectiveness and ease of use before and after hospital discharge. Moreover, conventional rehabilitation is performed using exercises, which are standard and not fully customized to each patient. The reproducibility of real environments and situations for neuro-rehabilitation is defined as ecological validity. It is considered one of the main features for making the rehabilitative exercise useful to re-learn specific information and for performing daily activities with the lowest effort.

The advent of Virtual Reality (VR) technology has given a new pathway for improving the ecological validity of neuro-cognitive rehabilitation in the cases of memory loss [12]. A VR application is based on the use of a head mounted display (HMD) to create the perception of a 3D environment, and of controllers or hand-tracking devices to interact with it. The environment can be shaped so that it resembles or reproduce a familiar place, e.g. the patient’s house, and it can be the setting for the rehabilitation serious games. This kind of games are not meant primarily to entertain but to reach an educative or health related goal. A serious game for neuro-rehabilitation can provide a 3D environment in which the patient is asked to perform tasks useful for the recovery process. Patients can be in the condition of either being able to recall lost memories or not. In the first case seeing and interacting with a familiar place could improve remembering quicker and better; in the second case when it is hard or impossible to recall past memories, the familiar place can be used, as if it was new, to train the patient easing his/her going back in a house s/he has forgotten but s/he virtually knows. The conventional practice to reintroduce a familiar place is simply based on showing pictures of the house and of known objects, while a 3D experience of an environment could potentially bring higher benefits. Given that the use of VR could improve the rehabilitation process, it is required to create the virtual house of the patient based on the 3D rendering of rooms and specific objects.

The 3D modelling of the virtual environment plays an important role to increase the ecological validity. The 3D environment of a serious game has to replace a real environment that should be shown to patient to help recalling his memory. Therefore, the 3D scene cannot be oversimplified and with unrealistic 3D objects and lights, but it is important to define a 3D modelling procedure to design the virtual environment in a as realistic as possible way. The scanning technologies can be used to acquire the 3D model of a real room as starting point to design the 3D interactive environment for serious games exploited by patients. The 3D scanner acquires the real shape and colors of a room by means of dedicated software applications that simplify the data management of the scanned point cloud to create the polygonal mesh. In this way, the patient will be able to navigate in his/her virtual house that will be used also as the setting for different kind of exercises, accordingly to patient’s condition and physician’s prescriptions.

To this is aim the development of effective serious games as rehabilitation tools is the core part of the research work, which comprehends the creation of a platform for semi-automatic games generation with specific patient's virtual home environment. The serious games are based on the use of VR technologies in order to make available a total immersive experience for patients. A specific procedure is designed for performing the 3D scanning acquisition of a room using a low-cost 3D scanner. First the paper presents the scientific background of the research context. Then, the designed procedure for the 3D scanning of rooms is described and the exploited tools to develop the serious games are introduced. Finally, preliminary results are evaluated and discussed.

2 SCIENTIFIC BACKGROUND

Several research studies confirm the potentialities of VR as a tool for rehabilitation of patient with memory loss. For example, Lecavalier et al. [3] introduced the use of a 3D virtual store to measure episodic memory skills with elder people. Each patient sees the 3D store through an HMD and, after a guided tour of the store, s/he has to remember where the items are in order to buy a specific shopping list. In this case, the 3D graphic is unrealistic and the technology used is very expensive. Similarly, Parsons and Barnett [11] developed a VR grocery store and the serious game makes available several mnemonic tasks the patient can perform by interacting with the elements of the 3D environment. The final results show a strong correlation between the outcomes obtained with standard episodic verbal memory tests and those ones reached using VR. Also in this case the store is shown through a HMD, but all the objects inside the virtual store are oversimplified. Cho end Lee [1] investigated the impact of VR to evaluate the cognitive functions during daily actions performed by patients who had an acute stroke. The improvements obtained with the help of VR were the same compared with those obtained with traditional approach, probably because the virtual environment used was not realistic.

In order to create realistic 3D environments, 3D scanning technologies have been already used for the acquisition of indoor spaces [5], [8], [14]. Acquisition can be performed in several ways according to the adopted 3D scanning system. There are two main categories for indoor acquisition. The first one is relative to professional 3D scanners that allows acquiring a whole home with a high accuracy. Lehtola et al. [10] presents a comparison among several professional systems to evaluate the procedure to obtain a high-quality polygonal mesh. Eight mobile 3D scanners have been considered and each one presented different weakness strictly correlated with their usability, such as double surfaces generation. Furthermore, this kind of scanners are very time-consuming and require complex calibration phase. The second category is relative to the last generation of low-cost 3D scanners. These devices are designed for entertainment purpose and thus, they have a high usability for people with no technological skills [1], [13]. Usually, low-cost 3D scanners such as Microsoft Kinect device or Structure Sensor, are connected to a laptop or a mobile device, and simple applications (e.g., Skanect) are available to obtain the 3D model of a room with no need of a complex set-up procedure. These solutions have been evaluated for 3D acquisition of indoor environments. Kalantari et al. [9] exploited a Microsoft Kinect v1 as 3D scanner to design a low-cost 3D surveying of indoor environments for the demand of a clearer comprehension about how a building is really done. Even if the 3D acquisitions are very useful for the 3D surveying, there is a low accuracy of specific objects (e.g., sofa, toilet bowl and sink). Dai et al. [4] developed a framework, named Scan-net, for 3D indoor scanning using a Structure Sensor mounted on an iPad. Scan-net can automatically recognize objects inside a 3D polygonal mesh by means of a trained convolutional neural network. The results are very interesting because the segmentation of 3D objects is very useful for the development of an interactive environments for a serious game, but it is only a software development kit (SDK) without a standalone application for people with no knowledge in computer graphics.

The goal of this research work is to define a modular and replicable procedure, implemented with specific hardware and software tools, to create VR serious games for mnemonic rehabilitation based on 3D environment replicating patient's real house. The 3D environments are gathered by means of a detailed 3D scanning of the rooms of the patient's house. The procedure is conceived in a manner that allows replacing the 3D virtual house of a patient with the virtual one of another patient in the easiest and quickest way, preserving the serious games logic and adapting it to the geometry of the new house.

3 DEVELOPED METHODOLOGY

To understand how VR technologies can be adopted to increase the level of ecological validity for memory rehabilitation, guidelines have been defined in collaboration with a medical team composed by a neuropsychologist and four physiotherapists in order to have a complete overview of needs of medical staff and patients during the rehabilitation process at the hospital and at home.

At present, the recovery of serious memory losses starts from regaining awareness of family environments in which patients continues to live after the brain injury, such as the hospital room during the period of stay or his/her home after discharging from the hospital. The traditional rehabilitation approach described by medical personnel is mainly based on the use of photos of family environments that are shown by the physiotherapists to the patient to make him/her learn how they are made. Although this approach can be easily used by physiotherapists, the minimal visual perception given by a single point of view home does not allow memorizing it in detailed way. Therefore, when the patient returns to his/her home, s/he is not able to recognize specific parts of the home and is totally disoriented when s/he has to move from one room to another or to find specific objects, (e.g. the patient does not know which is the cutlery drawer).

The ecological validity of the described approach is low. To increase it, innovative technologies may be exploited for a more effective and efficient rehabilitation process, such as VR and 3D scanners:

- Use of a 3D scanning system to acquire the house of each patient.
- HMD for VR to navigate in a natural and intuitive way.

As indicated by the involved medical personnel, the navigation of the virtual environment must stimulate the patient's interest, therefore proper tasks specifically designed to reactivate memory after the brain injury must be added.

As usual for any game, it is structured in different levels. The first level "Explore" has been designed for patients with important memory problems who have difficulties remembering their home environment. This level has been conceived to interact with all virtual objects, such as to open and close doors and drawers. Objects of common use will be positioned correctly behind or inside these supports, respecting the position of the real home environment. The main purpose of this level is focused on the reactivation of patient’s orientation in the home environment, on the recognition of it and on the possibility of practicing with the serious game.

The second level is called "Object by Object". This level is designed specifically for patients who cannot place the objects in their correct place in the room. In this case, the user must correlate the name of the object, that is suggested by the interface of the serious game with its place, by following a predetermined sequence. The aim of this level is to search for hidden objects in the virtual room that have been positioned by the programmer in the same position as the real environment. To understand which object is to be searched for, a textual information is used.

This level is subdivided into two sublevels called "Tutorial" and "Search". During "Tutorial", each virtual object to be found and its relative container are highlighted in red to suggest the position to the patient. Once the patient has gain practice, s/he can proceed to the sublevel "Search" where only the name of the object to be found is shown. No further information about the container of the object is given. Each searched object will turn green only after it has been identified to give a visual confirmation, but the target destination is not highlighted.

The third and last level, called "Treasure Hunt", is the most difficult. Patients must connect the name of the object to its position in the room, in this level the sequence of objects is random.

Also, in this case, "Treasure Hunt" level makes available a "Tutorial" level and a "Search" level. In the tutorial, the patient receives hints about the object to be picked and the container where to place it. After some trials using the tutorial mode, the user can move to the "Search" sub-level which is actually the "Treasure Hunt" game. Every time the patient starts a new game a new sequence of the objects is generated.

All levels are conceived with the aim to train the memory so that when the patient is discharged from the rehabilitation center, he will be familiar with the position of everyday objects in the room. In this way, he does not need to mentally go through the whole sequence to understand how to move and interact with objects, but he can remember their locations without external help.

Finally, the involved medical personnel highlighted the importance to measure performance parameters to evaluate the patients' improvements during the rehabilitation, such the time to find each requested object in the 3D home environment.

Figure 1 shows the main elements of the methodology architecture, and their interaction to gather a semi-automatic generation of personalized serious games.

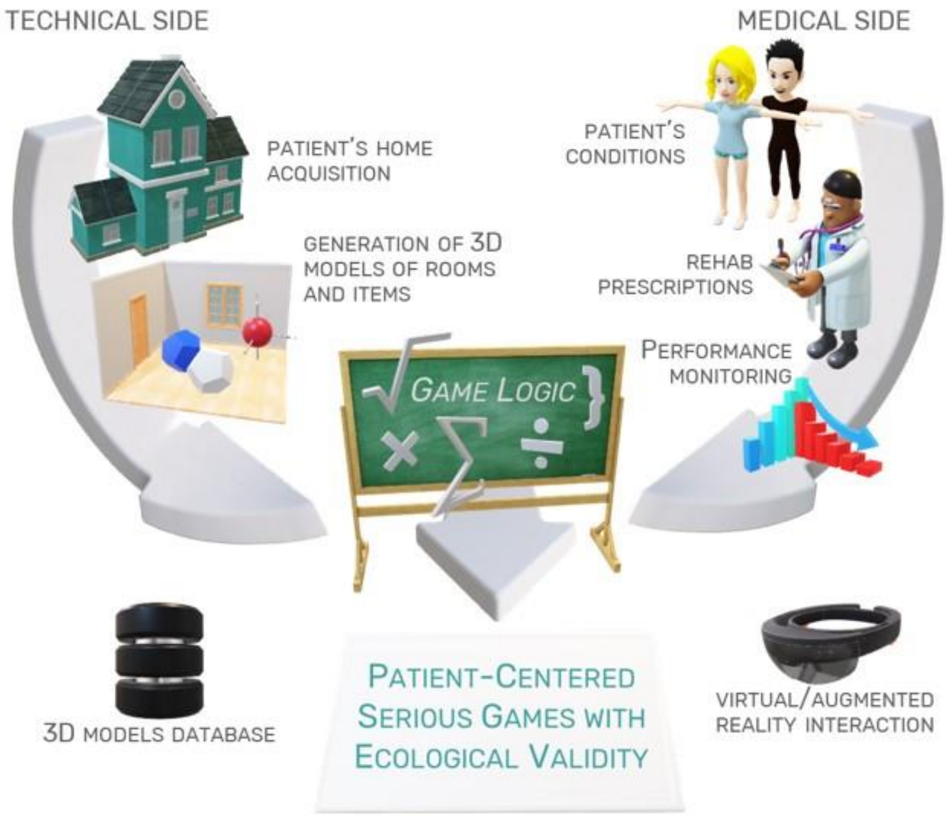


Figure 1: Methodology architecture and modules.

To embed the described features for the memory training in serious game, a game-logic has to be developed. It is the part of the software development of the serious game that generates a new series of events in the virtual environment when a set of conditions happens, such as changing the color of the found 3D object, playing sound alerts when patients does not find the correct object and activating a timer to measure how much time the patient needs to perform a task. The needed game-logic is unique and requires only to be applied to the 3D home environment of each patient. To reach this result, several technologies has been exploited and described in the next sections.

4 3D SCANNING PROCEDURE

According to the restricted budget constraints, the procedure is based on low-cost and consumer technology so that it can be affordable for the rehabilitation center and for the patients. The procedure has three main steps. The first consists in acquiring the environment following a set of guidelines designed to avoid loss of details and information. In the second step, a set of 3D modeling operations are adopted to prepare the model so that it can be used as the 3D environment for the interactive games. The third step consists in connecting the game logic to the 3D models for finalizing the game.

3D acquisition of environments

As mentioned in the medical guidelines, the acquisition of 3D indoor environment allows the generation of the 3D models of patient's home environment to navigate during the task for memory rehabilitation. After several scanning tests with different hardware tools (e.g., Structure Sensor and Kinect v.1 and v.2) for the acquisition of room geometry, we adopted Structure Sensor as a scanner and the commercial application Skanect to create the polygonal mesh of the room (Figure 2). Structure sensor has been chosen due to its low-cost and ease of use. It is mounted on an Apple i-Pad, while Skanect is automatically interfaced with the 3D structure sensor and makes available a set of virtual tools to easily generate the polygonal mesh. The acquired polygonal mesh requires a specific procedure to segment the point cloud in a set of 3D models representing the object present in the scene (e.g., table, chairs, sofa, wardrobes, kitchen sink) the user can interact with. This widespread and inexpensive solution resulted to be the best compromise among performance, cost and ease of use. Each 3D object inside the room has to be enough detailed in terms of shape and colors to be easily recognized by the patient.

Various tests have been carried out using Structure Sensor and Skanect in order to define a specific method and recommendations to be attended by the operator while scanning:

- Identify the main parts of the room (e.g., wall, doors, windows and furniture) and split the whole acquisition in a few smaller acquisitions, paying attention to the overlapping required for mesh alignment.
- Chose, together with the patient's relatives, some specific objects (e.g., a lamp, an armchair or a vase) that may help the patient to remember. Scan those objects separately to gather a better quality and to allow considering them as independent items.
- Objects and pieces of furniture, which are standard or less important for the patient could be neglected in the scanning phase since they can be easily replaced with 3D models available on the web or created ad-hoc.
- Take pictures of each room from different points of view to create a quick reference for item positioning in the space, and eventually for colors of standard parts.
- Consider light sources before starting the scanning process to reach a uniform lightning and to avoid critical conditions (e.g. direct sun light).
- Identify reflecting surfaces, mirrors or elements made of glass because they may create artefacts in the scanning process and consider substituting them with standard or 3D modelled parts.

By taking into account the above mentioned and some minor specific recommendations, the 3D scanning procedure allows drastically improving the quality of the virtual environment. Thus, these technical features allow creating a more realistic 3D model and saving time.

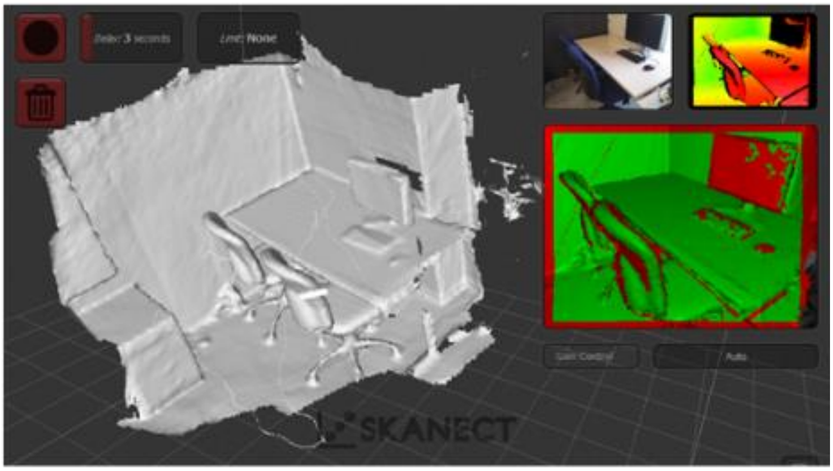


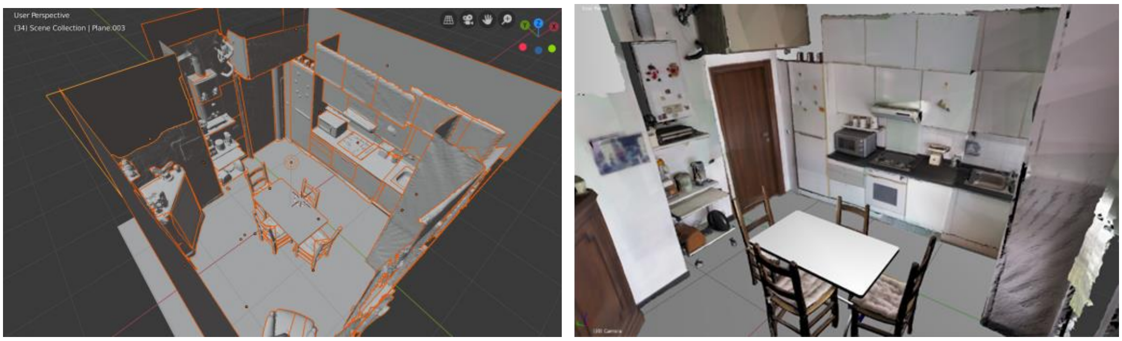
Figure 2: 3D acquisition of an office using a Structure Sensor and Skanect.

3D modelling operations: cleaning and repairing

After the room acquisition, a set of operations to get a useful and light polygonal model are recommended that are relative to a manual 3D segmentation of the 3D objects composing the room:

- Walls and floor should be replaced by flat surfaces with the same color of the real ones. This drastically reduces the size of the file of the mesh.
- Remove meshes of standard objects (e.g., chair, table, etc.) and replace them with the corresponding predefined 3D models.
- Check the mesh for errors and fill out visible holes to increase perceived quality of the virtual environment.
- Assemble all the cleaned 3D models; eventually merge them into a unique 3D model.

Blender has been used to perform the operations previously described. The final result of this step is the 3D model of a room and a database of 3D models re-usable also for the 3D modelling of other home environment. Figure 3.a shows a raw 3D kitchen ready to be assembled and the final 3D model with applied colored texture ready to be used for the development of the serious game (Figure 3.b).



(a) (b)

Figure 3: 3D modelling with Blender: the left picture shows a 3D kitchen during the assembly with specific 3D objects (table, chairs and burner) and the right picture depicts the textured 3D environment.

5 DEVELOPMENT OF SERIOUS GAME

Unity has been used to design and develop serious game. Unity is the most widespread game engine for a quick development of video games and permits to automatically import Blender projects. This means that every 3D modelling operation performed in Blender will be automatically updated also in Unity with no need of import/export of each used 3D model. This approach is suitable for our method that uses Blender for the 3D modelling segmentation of the home environment acquired as previously described.

The development with Unity of each serious game requires two main steps: (i) the design of an interactive 3D environment and (ii) the implementation of the game-logic following the medical guidelines previously described in section 3.

The design of an interactive 3D environment consists in making the segmented room responsive to the user interaction. For example, when the user performs a mouse click on a drawer, it opens as in the real world. This is possible thanks the specific 3D segmentation done in Blender, that allows creating (e.g., drawers, refrigerator and dishwasher) a specific 3D object for each drawer and door inside the room. The interactive access to containers gives the possibility to place simple 3D objects the patient can search as entertainment. This has been done by associating a 3D collider to each drawer or door. In Unity, a 3D collider is an event listener able to understand when patient performs the mouse click on a door and consequently opens it to search inside if there is a specific object. The use of 3D colliders and the segmented 3D environment is the basic functionalities that have been exploited to develop the game-logic for serious game according to the medical guidelines.

According to the medical guidelines, the videogame logic developed for memory-related issues is essentially the same for all patients with brain injury. Therefore, the game-logic of the serious game has been developed to be easily reused only changing the 3D segmented model of the home environment specifically acquired for each patient.

To develop the first level "Explore", it is not needed to develop a specific script for the game-logic. In this case, only the Unity scripts to open and close drawers and doors are exploited to navigate and interact the home environment and find simple objects (e.g., an egg, a cup and a glass) in several containers.

The level "Object by Object" required the same approach for the "Explore" level but, a specific script has been developed to manage the predefined sequence of the objects and both information and helps the user interface has to make available for correctly performing the task and achieving the final aim of this level. The developed script allows managing both the sublevels "Tutorial" and "Search". During the tutorial, all the containers with 3D objects inside have their doors of drawers highlighted in red color. Instead, the "Search" sublevel only gives textual information to the patient about which is the next object to be searched and how much time s/he is playing the serious game.

Figure 4 depicts the script interface that has been developed in Unity to manage the game-logic for the "Object by Object" level. The interface of the script allows using the generic virtual objects of the serious game (e.g., text labels, dialog boxes, buttons and a 3D objects) as parameters for the game logic. The first 3 parameters are relative to the textual information of the "Object by Object" level to help the patient. The script has to be associated to each object of the sequence known a priori. Therefore, the script requires to add as parameters the following list of virtual objects:

- The first 3D object of the sequence and the door of its container;
- The last object previously found;
- The actual object to be found and the door of its container;
- The last object of the sequence.

If this game logic is executed during the "Tutorial", every door of the containers associated to the 3D objects of the sequence will be highlighted in red color.

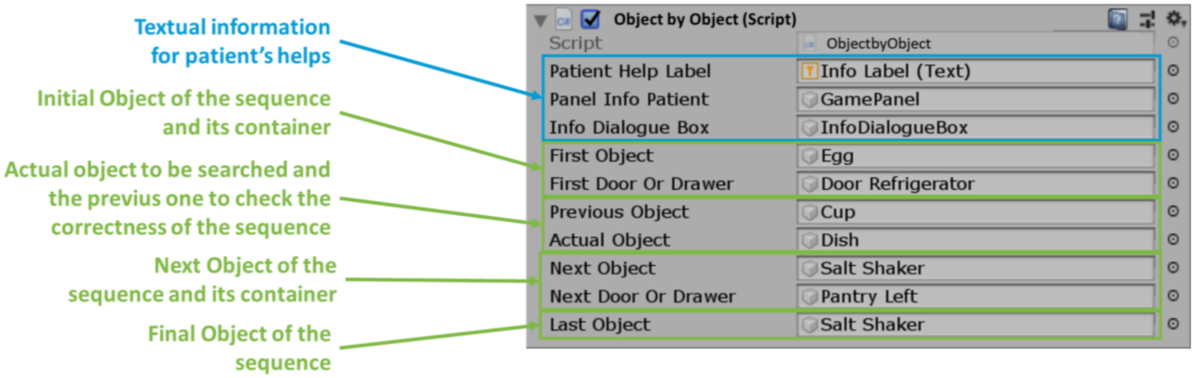


Figure 4: Unity script interface to automatically generate the sequence of objects defined a priori for the "Object by Object" level.

Figure 5 shows the Unity script interface of the game logic for the "Treasure Hunt" level. Also in this case, the first three parameters are relative to the textual information for the patient. The game logic for the treasure hunt level requires the list of object as initial parameters. For each 3D object, the game logic requires to identify the associated collider and the door of the container where the 3D object is placed. Given the list of 3D objects, the script automatically generates the randomized sequence the patient has to follow to complete the treasure hunt. When this game logic is executed in the "Tutorial" sublevel the door of the containers are in red color to help the patient to correctly find and memorize the correct sequence of the 3D objects. During the relative "Search" sublevel, no helps are given to the patient who has to remember where the interactive objects are and the correct sequence of operations to be performed.

In this way, the developer can exploit the available logic to develop the serious game for a new patient by changing only the 3D environment. Finally, the developed serious games can be rendered by using either traditional approach based on monitor, mouse and keyboard or using VR technology. The HTC Vive Pro has been chosen as HMD since it is simple to be installed and comfortable for patients. HTC Vive Pro also makes available a pair of controllers that can be used to interact with the 3D environment and can be easily interfaced with Unity using the software development kit SteamVR.

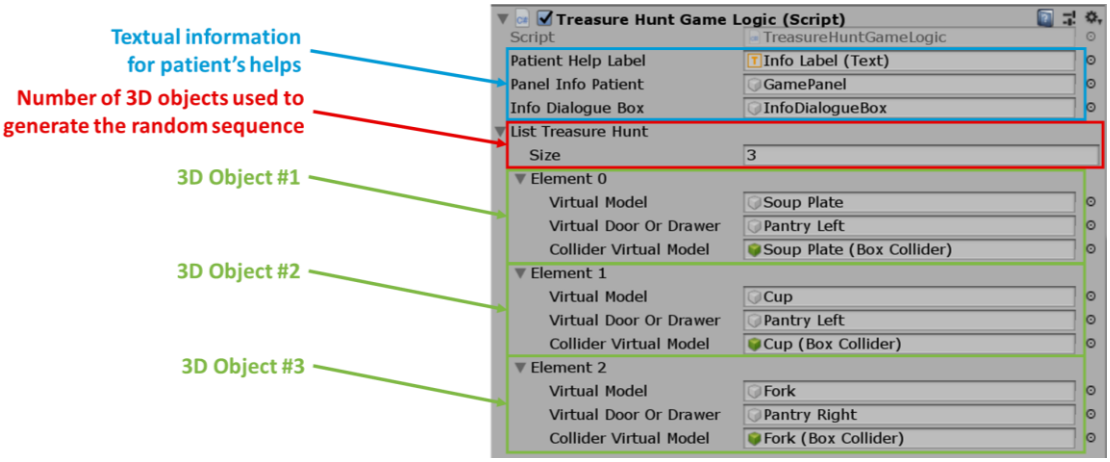


Figure 5: Unity script interface to automatically generate the randomized sequence of 3D object for the treasure hunt.

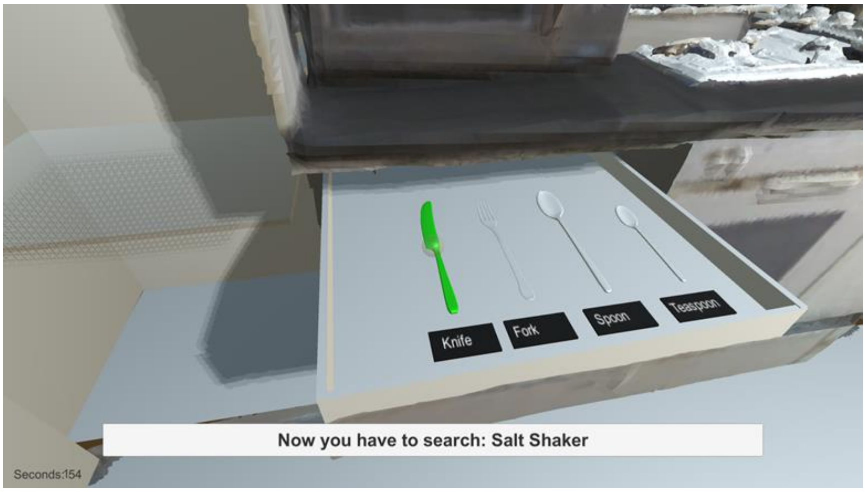
The importance of having a serious game available both for laptops and HMD represents a further added value of the presented solution. Indeed, some patients may partially loss their eyesight after a stroke and hence, the stereo 3D display of an HMD does not work well for them. Instead the use of a laptop guarantees a standard visualization of the 3D domestic environments from the screen and a level of ecological validity higher than the use of traditional pictures.

6 EXPERIMENTATION

Three real environments have been considered to evaluate the designed approach: a hospital room and two patient's kitchens. The hospital room has been considered because it is the first environment during the rehabilitation process. Furthermore, it allows the physiotherapist to teach the patient how to use the game and, eventually, the VR HMD having the same virtual and real environment. A kitchen is one of the main rooms in a house, it is important for patient's autonomy after discharge and it allows creating a number of exercises. As previously described, the Unity script about the video game logic and rules is already available to be exploited for both environments. The hospital room required three acquisitions, the left and the right sides of the room and a specific acquisition of the bed. Each part has been segmented to obtain doors of each container of the hospital room. A sequence of four 3D objects has been defined: a cup, a tea bag, a bottle of water and a teapot. This set of 3D objects has been used for each level of the serious game. The first kitchen is bigger than the hospital room and thus, five acquisition were necessary: one for each corner and one specifically for the entrance. Also, in this case, a further 3D segmentation has been performed in Blender to subdivide the doors of all containers inside the kitchen. Table and chairs have been considered standard objects and they have been deleted from the initial point cloud of 3D acquisition and replaced with predefined 3D models. Furthermore, the cooker and the armchair have been acquired separately. The second kitchen is the biggest one and six acquisition have been initially performed before the specific 3D segmentation performed in Blender to obtain the specific 3D containers and their door. For both kitchens, the sequence is composed by six 3D objects, which are: an egg, a knife, a soup tureen, a glass, a salt shaker and a plate. Figure 6 shows the tutorial of treasure hunt. Figure 6.a shows the red drawer containing the knife. The patient can use the mouse to click on the red drawer. After the click, the drawer opens and the patient can see the red knife that is the object s/he has to find as indicated in the label text in the lower part of the interface (Figure 6.b). If the patient clicks on the egg, it becomes green and the information label gives the suggestion to find the next object (Figure 6.c). Figure 7 shows the Unity script of the game logic exploited for this specific case study.

(a)

(b)



(c)

Figure 6: Find the knife: (a) the knife is in the red drawer, (b) several information helps patients to click the red knife and finally, (c) the game logic changes the color from red to green.

Table 1 shows the data relative to the time needed for each step of the procedure to acquire each environment and the file sizes of the 3D environment after the modelling operation performed in Blender.

For all the 3D environments, the most time-consuming task is the 3D modeling phase that requires many operations of cleaning and repairing of the acquired polygonal mesh. Indeed, although the hospital room is smaller than the kitchens, the 3D modelling step required similar time. Given the Unity script about the definition of the neuro-cognitive rehabilitation task, less than one hour for each serious game is required. The reached results have been also checked by the involved physicians who positively evaluated the high similarity of the virtual rooms compared with the real ones as well as the high potentiality of the presented solution for drastically improving the ecological validity of the rehabilitation processes for patient with severe memory loss.

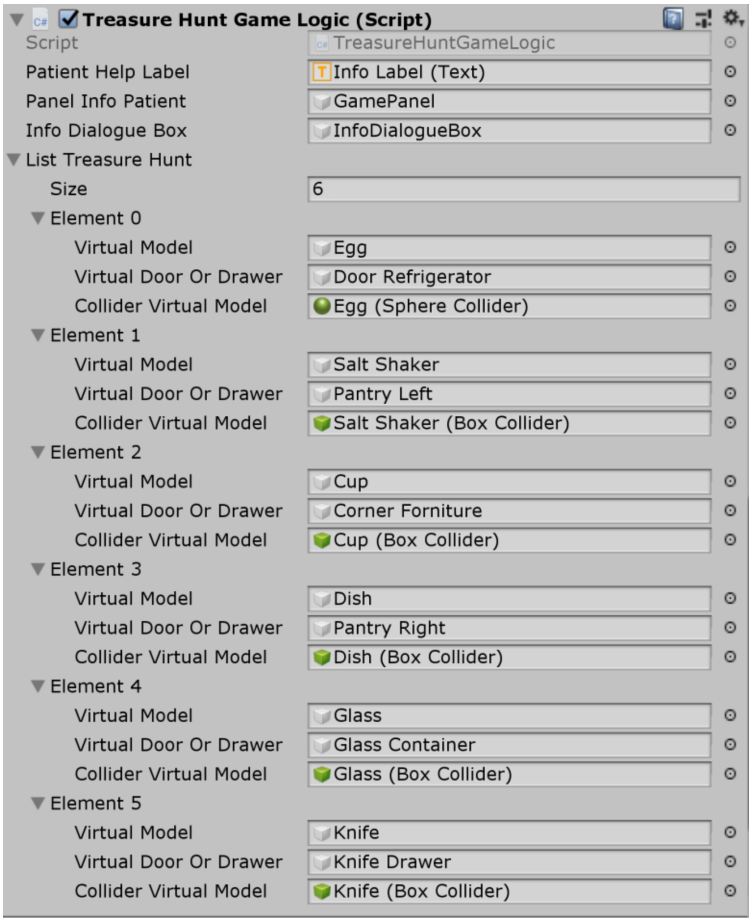


Figure 7: The Unity script for the game logic of the treasure hunt exploited using the first kitchen.

Environment	***3D Acquisition [h]***	***3D Modelling [h]***	***Serious Game [h]***	***Total Time [h]***	***File size [GB]***
Hospital Room	1.5	3.5	0.5	5.5	0.45
Kitchen #1	2	4	0.5	6.5	0.55
Kitchen #2	2.5	4.5	0.75	7.75	1.25

Tab. 1: Time required to apply the designed procedure and file size of each virtual room.

7 CONCLUSIONS

This research work presents a preliminary design of a specific procedure for developing serious-games for neuro-rehabilitation of patients with strong loss of memory after a brain injury. The designed procedure is totally based on free software tools and a low-cost scanner in order to foster its diffusion among rehabilitation centers and after patients' discharge. The procedure has been tested by creating three different serious games and the total time to create them can be approximated to a working day (i.e., less than 8 hours). The longest lasting task is relative to the modelling operations for cleaning and repairing the 3D acquisition. Physicians' feedback is positive since using a realistic 3D environment could drastically improve the ecological validity of the rehabilitation path. By starting from this preliminary evaluation, a future test has been planned to try the serious games with selected patients of the rehabilitation center. Furthermore, the physicians asked the possibility to show virtual avatars of parents or physiotherapists inside the 3D environment of serious game. To obtain these results, telepresence technologies will be evaluated and embedded in the presented solutions. Finally, the main bottleneck of the designed procedure is relative to the manual segmentation of the 3D objects inside the 3D environment and thus, more innovative solutions will be investigated to make this phase of the presented procedure as automatic as possible.

ACKNOWLEDGEMENTS

The authors would like to thank Erica Bonacina for her precious support in the 3D scanning procedure and Doctor Guido Molinero and Doctor Lorella Algeri of the Hospital Papa Giovanni XXIII, Bergamo, Italy, for their precious clinical contribution.

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