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

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Introduction:

Retrograde amnesia prevents a person from remembering events or information acquired before a serious event involving the brain. It is mainly caused by traumatic brain injuries [4], stroke, 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 [3]. In order to recover the lost memory, patients take part to a neuro-cognitive rehabilitation process guided by physiotherapists in a rehabilitation center. By the way, 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, or not fully customized to each patient. The reproducibility of real environments and situations for neuro-rehabilitation is defined as ecological validity. Ecological validity 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 [6]. 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 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 going back in a house he has forgotten but 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.

Several research studies confirm the potentialities of VR in this field. For example, Lecavalier et al. [2] 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. After a guided tour of the store, the patient 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 [5] developed a VR grocery

store. 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 Head Mounted Display, but all the objects inside the virtual store are oversimplified. Cho end Lee [1] investigated the impact of the use 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.
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. Then, 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.

Main aim:

The goal of this research work is to define a modular and replicable procedure, implemented with specific hardware and software tools, to develop VR serious games for mnemonic rehabilitation based on 3D environment replicating patient’s real house instead of using pictures or standards or predefined environment. 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 one in the easiest and quickest way, preserving the serious games logic and adapting it to the geometry of the new house.

Developed procedure:

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 consists of three main steps. The first step is the 3D acquisition of the environment. During this phase a set of guidelines have been identified to acquire the 3D environment avoiding 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 interactive games. Finally, in the last step, the serious games are developed.

3D acquisition of environments

After several scanning test with different hardware tools (e.g., Structure Sensor and Kinect v.1 and v.2) for the acquisition of the geometry of the rooms we adopted Microsoft Kinect v1 as a scanner and the commercial application Skanect to create the polygonal mesh of the room (Fig. 1.). This widespread and inexpensive solution actually resulted to be the best compromise among performance, cost and ease of use. The acquisition of an indoor space has to take into account a set of features to guarantee an appropriate level for the aim of this work. Each 3D object inside the room has to be enough detailed in terms of shape and colors to be easily recognized by the patient. Several scanning tests have been carried out using Kinect v.1 and Skanect in order to define a set of empiric guidelines and recommendations to be attended by the operator while scanning. Some of them are reported in the following list:

- 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.

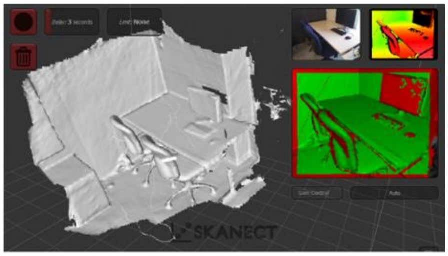

Fig. 1: 3D acquisition of an office using a Microsoft Kinect v1 device and Skanect.

3D modelling operations: cleaning and repairing

After the room acquisition, a set of operations are recommended to get a useful and light polygonal model:

- 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 those holes that look too bad to be visualized inside a virtual environment for serious games.
- Assemble all the cleaned 3D models; eventually turn them into a unique 3D model.

Some different 3D modelling tools available for free can satisfy the modelling requirements or to handle the mesh. Among them, the Blender package has been used to perform the operations previously described (Fig. 2.).

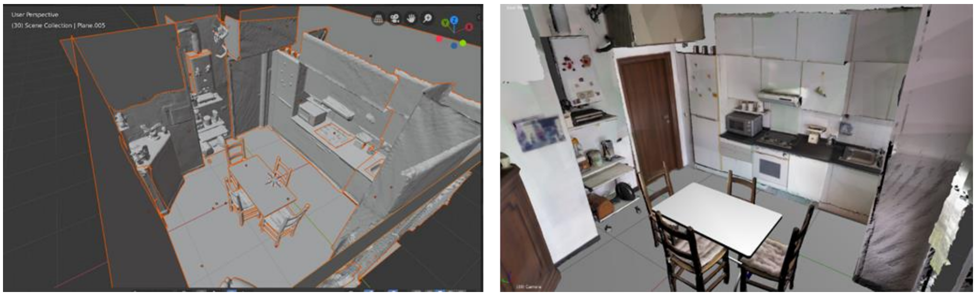

Fig. 2: 3D modelling with Blender: the left picture shows a 3D kitchen ready to be assembled and the right picture depicts the textured 3D environment.

Development of the serious game

Unity has been chosen to design and develop the serious game. Unity does not require high-level skills in computer graphics to implement an application. It also benefits from a complete integration with the most popular HMDs e.g., HTC Vive and Oculus Rift and interaction devices, e.g., leap motion controller.

The development of each serious game consists in two main steps: (i) the definition of the 3D environment and (ii) the implementation of the logic and the rules. This last step has been implemented in collaboration with physicians either to emulate traditional rehabilitation approach or to define new games.

The videogame logic developed for memory-related issues foresees three main rehabilitation tasks the patients has to perform. The first concerns the guided explorations of the whole environment to make the patient familiar with it. The patient can be guided by text labels and interactive objects, which are highlighted to be easily found (Fig. 3(a).). During the second task, the patient interacts with an ordered list of 3D objects according to predefined goal. All textual labels and the highlighted objects give information for performing the task (Fig. 3(b).). In this case, the patient has to memorize the textual instructions and the position where the 3D objects are placed. The last task is a kind of treasure hunt. No helps are given to patient who has to remember where the interactive objects are and the correct sequence of the operations to be performed (Fig. 3(c).).

The video game logic of the described tasks has been developed only once as a Unity script that can be embedded in every new Unity project. 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. The developed serious games can be rendered by using either traditional approach based on monitor, mouse and keyboard or using VR with an HTC Vive Pro.

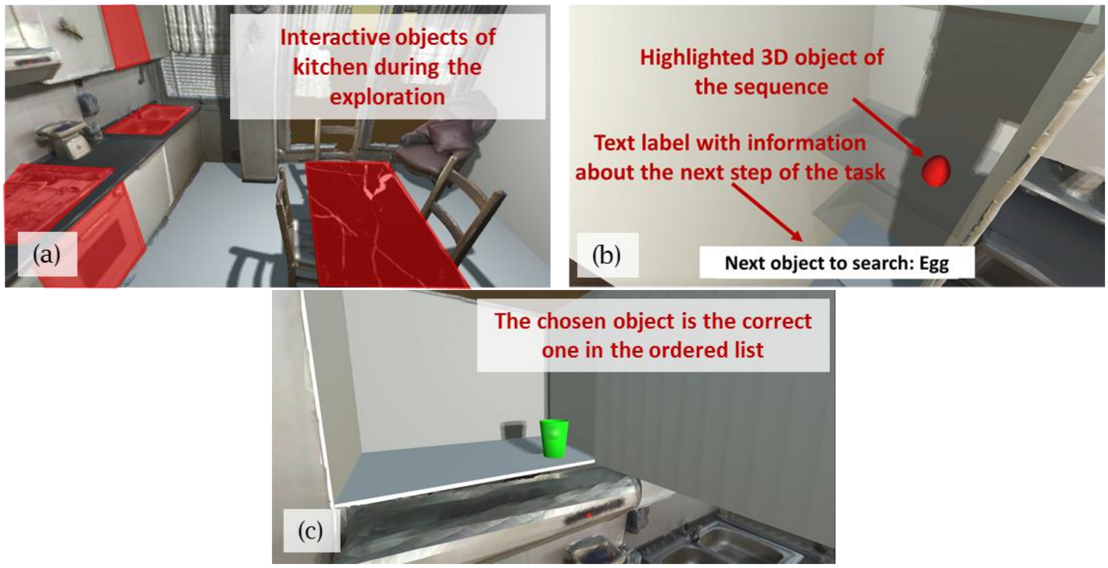

Fig. 3: Virtual environment including: (a) the virtual kitchen to be explored, (b) an egg found using helps and (c) a glass to be found during the treasure hunt.

Case studies

Two real environments have been studied: a hospital room and a patient's kitchen. The hospital room has been considered because it is the most familiar environment during the rehabilitation process. Furthermore, it allows the physiotherapist to teach to the patient how to use the game and, eventually, the VR HMD having the same virtual and real environment. The 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. A sequence of four 3D objects has been defined to create the task "Prepare a cup of tea". The kitchen is bigger than the hospital room and thus, five acquisition were necessary: one for each corner of the room and one specifically for the entrance of the room. Table and chairs have been considered standard objects and they are 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 sequence of the task is composed by six 3D objects to cook a fried egg. Fig. 2. Depicts how information and highlighted objects are shown to patients.

Tab. 1. shows the data relative to the time needed for each step of the procedure of each environment and the file sizes of the 3D environment after the 3D modelling operation performed in Blender. 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 kitchen, the 3D modelling step required similar time to be done. Given the Unity script about the definition of the neuro-cognitive rehabilitation task, about 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.

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	2	4	0.75	6.75	0.55

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

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 two 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.

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