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Article

Deploying Serious Games for Cognitive Rehabilitation

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Abstract: The use of games for non-ludic purposes, the serious games, is an interesting branch of science that has shown important results. With the advent of the pandemic that has made access to rehabilitation centres more problematic for patients with cognitive rehabilitation needs, the importance of being able to exercise these patients safely in their own homes has emerged strongly. Many studies show that immediate action and appropriate, specific rehabilitation can guarantee satisfactory results. Appropriate therapy is based on key factors to be taken into account such as frequency, intensity and specificity of the exercises. The aim of our work is to define a pathway for the creation of open source digital products that can allow access in any moment to a virtual environment through which patients who have suffered limitations in their cognitive abilities can exercise and recover all or part of these abilities in the shortest possible time. In view of the spread of IoT devices capable of easily monitoring various vital parameters, we propose with our system a low-cost and very efficient solution that can provide the doctor and therapist not only with quantitative data on the exercises performed (number and type of exercises, time spent, results obtained) but also an overview of vital parameters, so as to observe any states of agitation or excessive effort in completing the exercise.

Keywords: Virtual Reality, Augmented Reality, Serious Games, IoT, Web App, Blender, Unity3D

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1. Introduction

The use of games for non-ludic purposes, the so-called *serious games*, is an interesting branch of science that has shown important results [1,2]. Stroke is the second leading cause of death and disability in the world. It is a disease whose timely access to treatment is crucial to allow important improvements to recover motor and cognitive skills [3]. With the advent of the pandemic that has made access to rehabilitation centres more problematic for patients with cognitive rehabilitation needs (such as those who have suffered a stroke), the importance of being able to exercise these patients safely in their own homes has emerged strongly [4]. There is no doubt that at such a problematic time, poor digital organisation and not being used to organising processes with principles of digital sustainability has been a major detriment to the quality of life of citizens in many countries around the world.

Many studies show that immediate action and appropriate, specific rehabilitation can guarantee satisfactory results [5]. Appropriate therapy is based on key factors to be taken into account such as frequency, intensity and specificity of the exercises.

The aim of our work is to define a pathway for the creation of open source digital products that can allow access in any moment to a virtual environment through which patients who have suffered limitations in their cognitive abilities can exercise and recover all or part of these abilities in the shortest possible time. In view of the spread of IoT devices capable of easily monitoring various vital parameters, we propose with our system a low-cost and very efficient solution that can provide the doctor and therapist not only with quantitative data on the exercises performed (number and type of exercises, time spent, results obtained) but also an overview of vital parameters, so as to observe any states of agitation or excessive effort in completing the exercise.

In 1970 Abt coined the phrase "serious game" [6], which refers to games with a stated and thoroughly thought-out educational aim and are not intended to be played merely for entertainment. Nowadays, "serious game" is a widespread and specific phrase that refers to any video game-based learning and instruction (e.g.

business, military, medical, marketing). Serious games can place in both professional and casual contexts, and their target audiences range in age [7,8].

An increasing number of researchers and educators have worked to integrate serious games into schools [9,10]. For years, attempts have been made to establish the potential effects of this type of activity [11]: the question is how far games may be utilised for educational reasons [12,13]. Serious games provide a virtually immersive environment in which students can experiment and repeat tasks that are rare in their ordinary lives [14]. In fact, it is argued that their application in education can increase the likelihood of providing students with a real and deep form of learning [15,16]. The use of virtual reality and augmented reality seems to have a profound positive influence on activating specific areas of the brain; this gave rise to the idea of stimulating specific nerve centres to recover functionality that had gradually been lost due to illnesses or traumatic events [17].

So, in recent years, there has been an increase in interest in bringing healthcare services that can be operated remotely. The increased demand for healthcare services drove the development of easy and quick telerehabilitation solutions in various sectors. These services were designed to be reliable and routine (rather than just pilot experiments), and they are now even more vital in providing continuous and efficient health care [18,19]. Cognitive rehabilitation is a component of rehabilitative treatments that is committed to all patients who require ongoing cognitive function training because of injury (Traumatic Brain Injury, Stroke, Cerebral Palsy) or pathology (Alzheimer's disease, Multiple Sclerosis) affecting the Central Nervous System (CNS).

2. Related works

Telerehabilitation was initially used in motor rehabilitation, but it was later discovered to be beneficial in cognitive rehabilitation [20,21]. Specific cognitive capacities can be severely impaired due to various conditions and events, the majority of which are age-related issues like dementia, circulatory difficulties, head traumas, persistent mental diseases, or brain pathology [22–24]. Following a thorough neuropsychological examination that reveals the presence of cognitive deficiencies, neuro-psychological rehabilitation cycles can be carried out to enhance cognitive functioning, stabilise deficits, boost residual cognitive capacities, and reduce the path of decay.

Currently, there are three theoretical-practical currents of thought underlying the rehabilitation of neuropsychological deficits. The first one proposes to address the rehabilitation of cognitive processes through non-specific stimulation. The second, on the contrary, suggests that recovery must necessarily pass through specific stimulation of the disorder; this type of intervention can be differentiated into a restorative approach (recovery) or a substitution approach (compensation). The third does not deal with the specific disorder but proposes stimulating the residual abilities to overcome the difficulties and inhibitory effects, guaranteeing the most significant possible autonomy.

Virtual reality-based telerehabilitation systems use three-dimensional virtual environments to stimulate and obtain specific movements from the patient. The patient can view the virtual environment on the computer screen or utilise fully immersive devices, like Head Mounted Display, 3D movement sensors, and haptic devices [25–27]. Virtual reality technologies benefit rehabilitation because they can construct virtual worlds and employ activity repetition, feedback, and motivation to encourage learning of damaging abilities and subsequently convert them into the real world [28,29]. Video game-based virtual reality telerehabilitation systems are among those available. Thanks to the development of technology, nowadays, one can experience a virtual reality game very easily, given the availability of robust and low-cost devices. The created virtual environments reach such a level of realism and immersion that they positively affect telerehabilitation [30,31]. The usage of serious games enables patients with various infirmities to conduct exercises in a highly engaging and non-intrusive manner, based on multiple Virtual Reality situations, helping to increase motivation throughout the rehabilitation process [32].

We enter a world particularly rich in proposals, both playful-recreational and educational. As regards the latter, we can say that numerous solutions have been created, beginning with educational authoring tools, such as presentation, interactive exercises, algorithm exploration, problem-solving activities, and, more recently, social and educational games.

The Internet of Things (IoT) can be considered the dominant technology for integrating all of the medical resources of the community-based innovative and intelligent rehabilitation system in a network [33,34]. IoT refers to technologies that allow a wide range of devices to interact and communicate with one another via

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networking technologies [35]. The monitoring application's front-end, which functions similarly to a network manager, manages to store, aggregate, integrate, analyse, and modelling data received. Such systems in healthcare employ a collection of networked devices to build an IoT network targeted to health assessment, including patient monitoring and automated identification of circumstances requiring medical action [36,37]. The entire network receives data from various sensing devices via software, which offers the necessary interoperability and security in the IoT paradigm for healthcare.

Moreover, the wide diffusion of wearable devices or beacons-sensors system [38] has considerably increased the possibility of monitoring bio-signals, both for diagnostic and therapeutic purposes [39].

3. The proposed system architecture

The system we developed requires the patient to use a mobile or fixed device to access a Web App containing a set of exercises planned by the therapist and the doctor according to the type and severity of the patient's cognitive deficit. The use of immersive devices would increase the effectiveness of the exercises themselves but is not indispensable. In fact, the exercises are characterised by being placed in a very poor virtual context from the realistic rendering of the virtual world. When the doctor and therapist set up the exercise, they can include pictures of people, objects or other things that evoke memories in the patient to make the exercise even more effective and engaging.

3.1. Use of IoT devices and Edge Computing

The use of IoT enables the doctor to monitor several vital parameters of the patient in order to be able to track the state of anxiety and performance stress and provide further helpful information. The large quantity of data collected may be analysed by computational resources located close to the patient to minimise the data transmitted to the Web App server, following the paradigms of Edge Computing [40]. We used the Fitbit Sense smartwatch device to keep some of the patient's vital parameters under surveillance, like heart rates, tissue oxygenation SpO2, respiratory rate, skin temperature, and aFib (atrial fibrillation) signals. The monitoring we carry out takes place in the few minutes before exercise (value set by the therapist), during exercise, and a few minutes after exercise. In this way, we can obtain data to compare the trend of the parameters in a state of calm and concentration state.

3.2. The Web App

The Web App consists of the front-end environment accessed by the patient, which contains the daily exercise list, and the environment reserved for doctors and therapists, where the exercise program for the specific patient is set up. The Linux server that delivers the Web App is based on a Debian distribution within which a Docker container orchestration service runs[1]. One of the features we focused on most was the compatibility of our applications with the most significant number of devices on the market. Indeed we tried to create a software environment that did not require exceptionally high computational power.

3.3. The exercises

The exercises we propose are created mainly using open-source software. Blender is used to create the objects with which the virtual world is made, while Unity is used to assemble the virtual interactive environment[2]. The open-source OpenCV libraries are used to process images and to implement the exercise *connect the dots*. The open-source JavaScript language and Python are used for creating the script programs.

4. Discussion

We propose a series of exercises for cognitive rehabilitation. Thanks to these practices, the patient can recover necessary skills and relieve himself from an inability to perform essential daily activity functions. We

[1] https://www.docker.com/

[2] Unity is not open source. However, its usage is free for environments which produce an income of fewer than 100,000 USD, so it is free for medical applications

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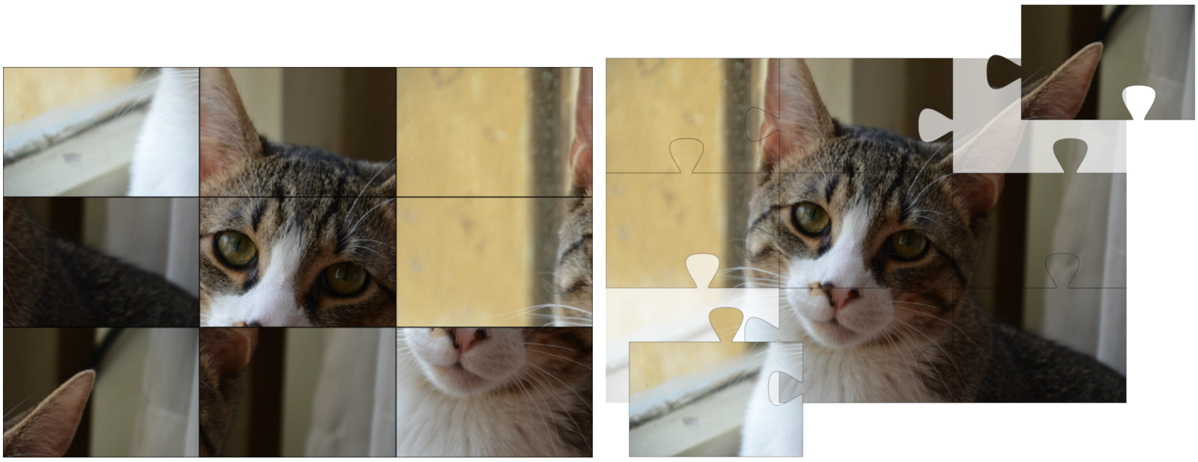

(a) This type of puzzle has the tiles all with the same shape

(b) This type of puzzle has the tiles that must fit together with each other

Figure 1. The two types of puzzles are shown

aim to outline a methodology that allows with relatively little knowledge to implement other exercises, also in the light of patients' experiences on the one hand and medical staff on the other.

4.1. Solving a puzzle

Solving a puzzle based on reassembling a picture from its pieces is important for stimulating visual and motor coordination. In this type of exercise, the patient ought to be able to determine the order and position of the pieces. The patient must also coordinate hand and finger movements to select the puzzle pieces and position them correctly. In order to make the exercise more enjoyable, images are used that have an emotional connection to the patient's life history, e.g. photos of the family, pets with which there is a strong emotional bond or pictures from childhood. The application has two separate interfaces: one for the doctor and the other for the patient. The doctor has the task of setting up the exercise, selecting a suitable image and the number of tiles that will make up the puzzle. After that, the software breaks down the image into several tiles that agree with those set by the doctor and then randomly shuffles them on the screen. Next, the server generates a public URL, which can be sent to the patient. When the patient opens the URL, he or she will immediately find the exercise ready to be performed, with a very short loading time, as the software is entirely realised in HTML5, JavaScript and CSS. The additional components that the user's browser will have to download are a JavaScript script and the JPEG image.

The exercise is also customisable, as the doctor can also choose the shape of the puzzle tiles. The choice can be made between rectangular tiles that are all the same shape, as shown in Figure 1a, or dowel-shaped tiles, which must be fitted together, as shown in Figure 1b. The doctor can choose whether to give the patient the version with rectangular tiles or the classic version. The patient interface provides the puzzle to be put together and the stopwatch. The stopwatch turns on automatically as soon as the puzzle is started. After a congratulatory message, the time taken will be saved in the database and displayed when the puzzle is finished. In the doctor's and therapist's interface, there is a report that will show the exercise time for each image used, providing the opportunity to analyse the patient's progress and see his or her progress over time.

In Figure 2 a patient is shown solving a puzzle using the application.

4.2. Connect the dots

The second exercise is called *Connect the dots* and has a slightly higher degree of difficulty than the previous one. To complete the exercise, one must connect the dots identified by integer numbers, starting with the number 1 and continuing in ascending order up to the maximum number on the screen. This exercise aims to stimulate the patient's logical-mathematical skills. In fact, he/she must identify the numbers, understand their mathematical

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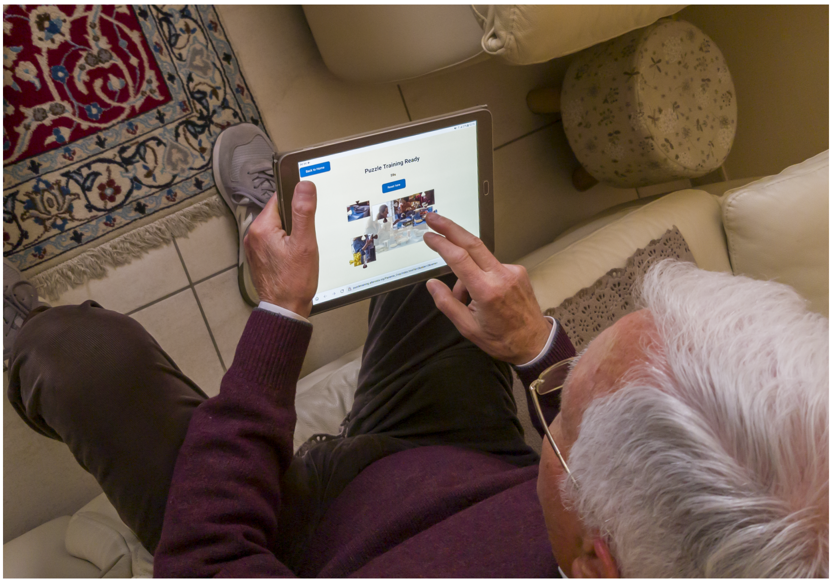

Figure 2. Patient during the puzzle resolution

meaning, try to deduce the final figure, and then use visual and motor coordination to move the finger across the screen until the exercise is completed. There are also two graphical interfaces in this exercise; the doctor's and therapist's interface and the patient's interface relating to the execution of the exercise. The doctor's interface allows indicating an image on which to create the series of dots to be joined to reproduce the main lines. Images suitable for this type of exercise are predominantly black and white, with a low level of detail and graphic complexity. The shapes we recommend are the simplest, such as regular polygons, animal drawings or children's colouring figures. The Figure 3a shows an image with dots to be joined. The Figure 3b shows the image with the dots connected.

Once the doctor has selected one of the predefined images or has uploaded an image of his preference, a JavaScript script will be executed. After analysing the image, it will extract features using the OpenCV graphics library. In fact, comma filters are applied to bring out the contours and the most defined parts of the image. Then the result obtained is processed in such a way as to eliminate the segments and replace them with a sequence of dots to which labels characterised by integer numbers are associated. The doctor will then see the result obtained and decide whether the complexity level is acceptable. Suppose the image obtained is evaluated as too simple or too complicated: in that case, the number of dots shown on the exercise can be adjusted by the doctor or the therapist using a slider. These adjustments allow calibrating the exercise finely. Following each adjustment, a function associated with the onChange event of the slider is executed. The function executes the script again, which analyses the image and determines its representation in points and segments, adjusting the complexity according to the doctor's preference. Once the doctor has finished setting up the exercise, the system will provide a URL that can be given to the patient.

Once the patient has received the URL and clicked on it, the exercise page, which has already been set up correctly, will open. The exercise page has a timer, a picture with the dots to be joined, and a button to stop the exercise if the patient does not want to finish it. The timer starts automatically as soon as the patient connects the first two dots. The web page has a very short loading time as it consists of a JavaScript code, which manages the timer and the detection of finger touch input, and a canvas on which there is a monochrome JPEG image. The exercise can be interrupted in two cases: the first case occurs when the patient completes the joining of all the dots present in the image; in the second case, the patient has prematurely interrupted the exercise by pressing the exit button presented below the image. The interruption of the exercise involves sending the result achieved by the patient encoded via a JSON list to the central server, which is stored in the database. The doctor or therapist can then see the level reached by the patient, how many dots he/she managed to connect correctly, and the time taken. If the exercise has been performed several times, the records of previous attempts are also reported to show any progress. Figure 4 shows a patient performing the exercise of connecting the dots on his tablet.

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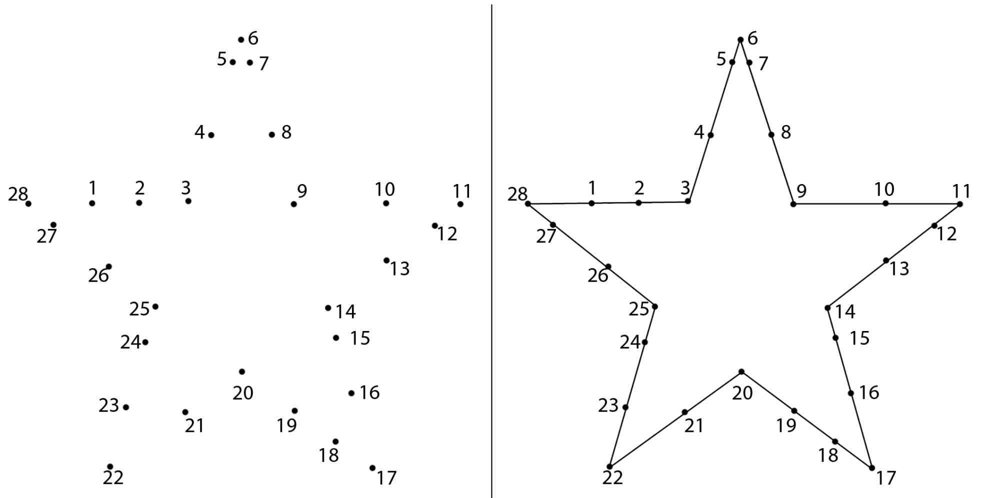

(a) Begin of the exercise with the dots to be connected

(b) The exercise completed, with the dots connected

Figure 3. One of the figures used for the connect the dots exercise is shown

4.3. Key turning in the lock

The exercise that is now presented was realised by exploiting immersive virtual reality techniques. This exercise involves the patient wearing a VR visor and using hand controllers capable of transforming the wrist's movement into actions that are performed in the simulated environment. The patient will be in a room, have to pick up a key, locate the door and its lock, and finally, after approaching it, insert the key into the lock and rotate it. The door will open at the end of the rotation, and the exercise will be finished. Using Unity and Blender, a domestic scenario was created, with a room and various objects in it. All objects in the scenario were created using the Open Source software Blender [3]. The objects were then arranged in a scenario using Unity software [4]; the scenario was then configured to exploit the potential offered by immersive visors, such as the HTC Vive. This exercise is designed for patients who have neuromuscular problems and need rehabilitation to recover motor coordination of the hand. In Figure 5 can be observed the main step executed by a patient performing this exercise.

5. Conclusions

This research work aims to contribute to the development of sustainable digital technologies that offer patients with a cognitive impairment the possibility of practising from home using a tablet, smartphone or desktop computer. The patient must be able to exercise consistently and be monitored for his/her progress while performing the tasks assigned by the doctor. Moreover, the doctor ought to control patients' vital parameters to be able to quantify the emotional stress and any difficulties arising during the exercises. With the actual development of technology, cost-effective devices connected to smartphones and computers, which can monitor an increasing number of the patient's parameters, the doctor has got an increasingly detailed picture of the person's physical and emotional condition while performing the exercises. Such an approach is of enormous benefit in difficult times, such as we have experienced with the COVID-19 pandemic. There is no doubt that it would be essential to use everything we have learned over the past two years while living in absolutely precarious conditions and often unable to reach the designated places of care.

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3 https://www.blender.org
4 https://unity.com

Figure 4. Patient solving the *connect the dots* exercise

6. Author contributions

Conceptualization, Damiano Perri, Marco Simonetti and Osvaldo Gervasi; Data curation, Damiano Perri, Marco Simonetti and Osvaldo Gervasi; Investigation, Damiano Perri, Marco Simonetti and Osvaldo Gervasi; Methodology, Damiano Perri, Marco Simonetti and Osvaldo Gervasi; Software, Damiano Perri, Marco Simonetti; Supervision, Osvaldo Gervasi; Validation, Damiano Perri, Marco Simonetti; Writing – original draft, Damiano Perri, Marco Simonetti, and Osvaldo Gervasi; Writing – review & editing, Damiano Perri, Marco Simonetti, and Osvaldo Gervasi.

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Abbreviations

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(a) Step 1: The room in the virtual environment

(b) Step 2: The patient identifies the key, and picks it up

(c) Step 3: The patient inserts the key into the lock and rotates it

(d) Step 4: The patient opens the door

Figure 5. Main steps for performing the exercise *key turning in the lock*.

The following abbreviations are used in this manuscript:

aFib	Atrial Fibrillation
AR	Augmented Reality
CNS	Central Nervous System
CSS	Cascading Style Sheets
HTML	HyperText Markup Language
IoT	Internet of Things
JPEG	Joint Photographic Experts Group
JSON	JavaScript Object Notation
OpenCV	Open Source Computer Vision Library
URL	Uniform Resource Locator
VR	Virtual Reality

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