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DESIGNING ACCESSIBLE VR GAMES TO ASSIST STROKE REHABILITATION

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ABSTRACT

VR games have become an important part of rehabilitation therapy for stroke survivors particularly to recover limb movements. The success of recovery is dependent on the repetitive movement of limbs over a considerable amount of time. It has been shown that VR game-based rehabilitation can offer promising results for repetitive movements as compared to conventional therapies. To improve the effectiveness of VR games it has been argued that – specifically designed games offer better stroke rehabilitation to keep patients engaged and motivated. This paper presents the development of non-immersive accessible VR games designed for upper limb movements without overloading patients. These games are designed based on the suggestions received from clinicians and physiotherapists. The games provide a non-immersive yet quite engaging environment with real-time scoring of performance. A preliminary test of the games with the exoskeleton robot and discussions are presented.

Keywords: Virtual Reality, Stroke Rehabilitation, VR Games, Medical Robotics, Azure Kinect

1. INTRODUCTION

The latest data from Stroke Association UK shows that a stroke strikes every five minutes, 100,000 people have a stroke each year and there are 1.3 million stroke survivors in the UK. Out of Stroke survivors, 65% suffer from various impairments such as physical, psychological, and cognitive functions [1]. It has been well established that stroke survivors who suffer from impairment of upper limb movement can significantly recover their mobility from prolonged and regular physiotherapy [2]. The repeated range of movements is the key to restoring neuroplasticity and arm functions. Conventional movements supported by therapists are time-consuming and repetitions can be very stressful [3]. Patients do lose motivation and therapists do not have sufficient time for longer rehabilitation therapy, therefore task-specific interactive game-based VR systems may play a key role in stroke rehabilitation [4]. VR-games-based physiotherapy could offer stroke patients more engaging and encouraging experiences in recovering hand functions [5]. There are many VR games available in the market both immersive and non-immersive, however, the immersive games have requirements of additional gadgets and their attachment to patients. Off-the-shelf video game consoles, like Wii, PlayStation, and Microsoft Kinect, have been increasingly used as tools for rehabilitation as they are inexpensive, easy to use, and support full-body motion control [6,7]. The study in [8] suggests that exoskeleton robot-based rehabilitation has been effective in the treatment of upper limb recovery after stroke. Virtual reality and gamification systems have been taken up for rehabilitation to increase engagement and motivation with robotic rehabilitation [9,10]. The effects of VR games and gamification with exoskeleton robots for post-stroke rehabilitation are considered in [11,12]. Several games have been developed for rehabilitation and assessments, but off-the-shelf games are not suitable for stroke rehabilitation [13]. The VR games specifically designed for stroke rehabilitation are sparse. In this paper, we focus on the development of non-immersive VR games using upper-limb exoskeleton robots. Exoskeleton robot-based VR rehabilitation systems can be useful in assisting patients and saving clinicians time by offering physiotherapy sessions with minimum supervision and on several patients at a time. We present two custom-designed VR games on non-immersive principles specifically for upper-limb recovery supported by an upper-limb exoskeleton robot.

2. MATERIALS AND METHODS

The development of VR games is based on several discussions with clinicians and physiotherapists specifically for stroke rehabilitation using upper limb exoskeleton robots. The exoskeleton robots assist when the patients are not able to play these games on their own. We checked what could be the key requirements for VR games to be practical and acceptable to patients. The feedback we received was that the VR games should enable patients to practice movement and allow interaction with a variety of objects of different shapes and sizes. The games should be capable of changing the difficulty levels and the environment should be safe and engaging as well as challenging with continuous monitoring of performance. There should be minimum use of visual attachments or heavy devices like head-mounted displays (HMD) should be avoided. Such attachments add additional burden on patients to manage during rehabilitation training and are particularly not suitable when the patients are of older age and have some vision impairments following stroke. They cannot play for longer sessions due to physical discomfort and may develop symptoms like headache, real-world isolation, and motion sickness.

2.1 VR Game Platform for Rehabilitation

After considering these requirements and keeping patients engaged for longer sessions of rehabilitation training, we developed non-immersive VR games for the upper limb supported by an exoskeleton robot. Fig 1 shows the building blocks of our VR Games for Stroke Rehabilitation using Unity3D as a Game Engine. The exoskeleton robot provides both assistance mode and free mode to play VR games depending on the assistance level requirement of the patients. The data communication between the robot and VR games is exchanged through a bridge program which sends and receives data between the robot and the Unity game. The upper limb exoskeleton robot with VR games will be useful for physiotherapy centers where patients may need assistance to exercise and for patients who want to do a longer therapy session without much supervision. The system may also be useful for situations like Covid-19 where remote diagnostics and non-contact rehabilitation are preferable. The VR games using the exoskeleton robot will help physiotherapists guide and offer consistent rehabilitation routines without much physical interaction.

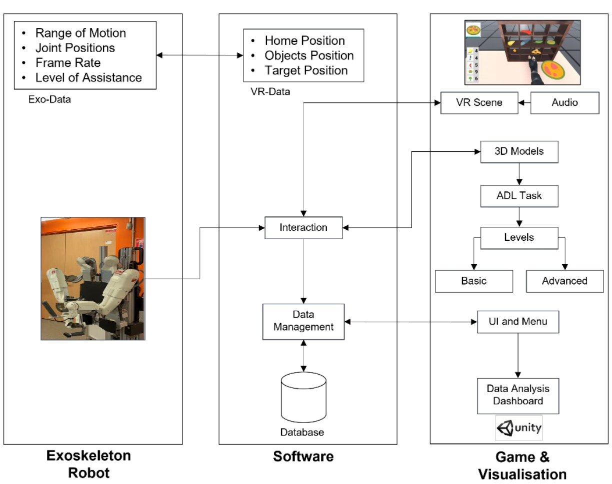

FIGURE 1: BUILDING BLOCKS OF VR GAME

The Game development was done on the unity environment. Unity is a multi-platform gaming engine, which can be used to create games for many platforms. The games were developed to track the upper extremity movement. Although the gaming environment is 3D the user interface is only 2D and one player can play the game at a time. A Windows 10-based laptop with 32 GB RAM and an NVIDIA graphics card was used to design the games. All the developed games are intuitively designed for engaging activities of daily living (ADL). Fig 2 shows the elements of the developed VR Games, this shows the design features and contents of the game considered.

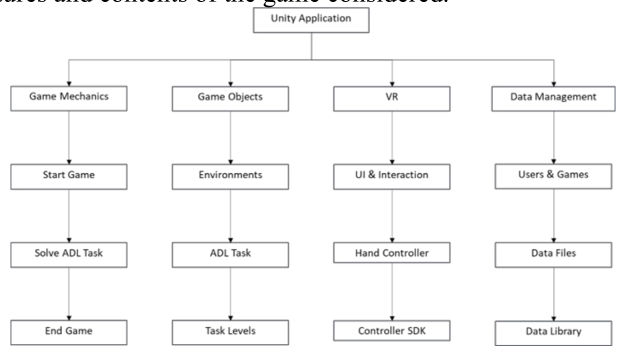

FIGURE 2: ELEMENTS OF THE DEVELOPED VR GAME

2.2 The Rationale of Game Design

In the early phase of stroke, intensive and repetitive therapy with functional movement has been shown to bring positive outcomes. The designed VR games are designed to be effective in engaging as well as motivating patients to practice functional movements. The main difficulty encountered during rehabilitation training is to engage patients to play the game and motivate them to keep playing; we have attempted to fill this gap. It is important to consider stroke patient's abilities to create more engaging game designs. With this objective in mind, the VR game should be designed to be entertaining and keep the patient motivated to achieve more repetitions similar to conventional therapy of 'pick and place'. The games should involve meaningful tasks such as activities of daily living (ADL), appropriate range of motions, adaptable level of difficulty and positively rewarding for their performance. On this basis, we conceptualized two different indoor/outdoor VR games, mostly based on ADLs but more to keep patients engaged. These games are designed with increasing levels of difficulty or complexity that may help in improving the cognitive and memory functions of patients. The designed VR games are named (1) Fruit Catcher and (2) Pizza Recipe.

Game 1: Fruit Catcher

The Fruit Catcher game in Fig 3, is a non-immersive outdoor VR game. In this game, the patient must catch fruits that fall from the tree i.e., the top of the screen. The location of the fall is randomly generated which means the participant is not aware in advance of where the fruit is likely to fall. They have to keep waiting for the initiation of the fall and then have to move their arm to a location to catch the fruit. The game is designed in a way that fruit can fall in the same plane parallel to the frontal plane of the user and at different distances from the user within a reachable distance of the user's range of motion. The position of the falling fruits is adaptable to the patient's range of movement. To identify the depth of the object within the game environment a shadow of the object on the surface below the hand is displayed since the display is on a 2D screen. If depth perception is difficult, falling objects can be made to stay in the air and users can reach the object and catch it.

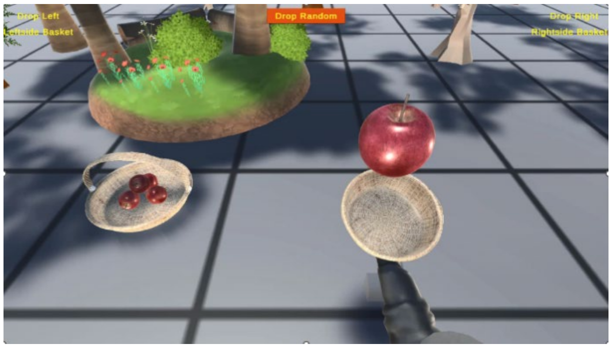

FIGURE 3: FRUIT CATCHER VR GAME

Depending on the level of difficulty set in the game, the basket size to catch fruits, speed, distance, and time between successive objects falling can be varied. Each level of the game has different types of fruits to make the game more entertaining as shown in Fig 4. To make the game more entertaining and engaging, this game has three levels of difficulty; level 1 has Apples, level 2 contains Oranges and Lemons, and level 3 consists of Strawberries, Berries and Cherry fruits. Each level has a limited number of fruits to catch and have a different scoring system implemented, catching cherished fruits scores higher. To engage the patient the score points are displayed at the end of each level of the game. The final score is calculated based on the number of objects caught and the difficulty level of the game. This game can be played with either the right arm or left arm and the bilateral mode is also possible with two arms to catch the objects.

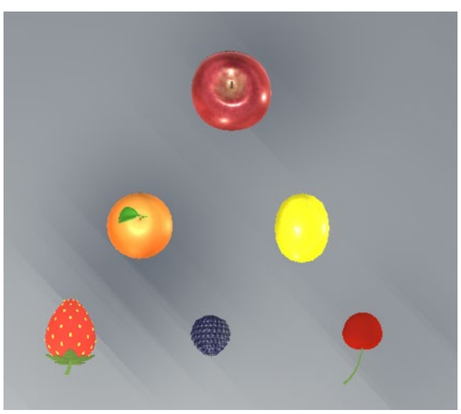

FIGURE 4: FRUITS USED IN THE GAME

Game 2: Pizza Recipe

The Pizza Recipe is a non-immersive indoor VR game. This game is designed to help patients practice ‘pick and place’ (reach, grasp and release) actions, however, this has further potential to improve cognitive, memory and motor functions since it involves shape recognition, numeral conformity and arm movement. The game is to pick up particular pizza recipe ingredients from specific locations on the shelf in required quantity and place them on the pizza base. The patient must follow the recipe with the steps displayed on the screen, the pizza recipe along with its ingredient menu is shown on the screen. This game has a different variety of pizza recipes to overcome boredom and engage patients for longer sessions as shown in Fig 5.

FIGURE 5: PIZZA RECIPES IN THE GAME

This game also has three levels, and each level of the game is divided into the type of pizza recipes and the number of ingredients required. Points are awarded to the user at each level and scored based on the time taken to complete the pizza recipe with the right ingredients. The ingredients are picked up separately one at a time to help the patients to do more repetition of functional movements. To support this idea only one item of each ingredient is placed on the shelf. once the user has picked up the particular item and placed it on the pizza dough it keeps regenerating that item on the shelf until the count of that item has been completed. Each pizza recipe has particular ingredients with a fixed number of items and each item is also numbered with counts in the ingredient’s menu. This guides the user to pick up that particular item as many times as required as shown in Fig 6.

FIGURE 6: PIZZA RECIPE VR GAME

3. RESULTS AND DISCUSSION

We conducted an evaluation test with expert and non-expert healthy users, using the ABLE7D exoskeleton designed by CEA-List in Palaiseau, France, and manufactured and commercialized by Haption as shown in Fig 7. CEA-List ABLE7D has 7 motorised DOFs (Degrees of Freedom) and can operate in both assistive and free modes. In assistive mode, The VR game sends the wrist position to the exoskeleton robot. Based on game rules the next position data of the wrist is sent to the robot using the bridge program. The robot uses this wrist position data (end effector) and sends back the joint orientation data of the shoulder, elbow, and wrist to the virtual arms in the VR games. Based on the data received from the robot the corresponding virtual arms are updated in the unity game environment. At present, only shoulder, elbow and wrist joint data are used in VR games. The position and orientation data received from the exoskeleton robot which is in the right-hand coordinate system is converted to the left-hand system of unity inside the VR games and the corresponding game object and target positions data in the game is converted to the right-hand system and sent to the exoskeleton robot.

FIGURE 7: USER WITH CEA-ABLE7D EXOSKELETON

Our VR game interaction is implemented using collision detection of the virtual arm with other objects in the Unity game environment. The velocity and level of assistance are controlled by the exoskeleton robot. In free mode, the user has control of the robot and is required to move the exoskeleton robot arm to play the VR games. Based on the rules of each game user has to move his arm to the required positions in the game environment. The collision detection in the fruit catcher game is checked once the user with the basket on his virtual arm touches the fruit/object and if the object is inside the basket. Once the fruit is successfully caught it is transferred to the big basket on the ground. In the pizza recipe game once the user reaches the object position according to the game mechanics the collision detection is checked, and the corresponding object is attached to the virtual palm of the user. Similarly, once the user with an ingredient object reaches the target position (pizza dough) the object is detached and placed in the target position with an offset from the center of the dough within its bounding area. The initial position of the virtual arm's wrist is considered to be the home position of the user. This home position is used as the starting and ending position for the user after each pick and place task.

A user interface for the therapists/clinicians is provided which consists of Exoskeleton and VR Games menu. In the exoskeleton menu, the calibration of the robot and range of motion or safe workspace of the user is defined. This workspace information along with arms choice, and assistance level information is sent to the VR game. In the VR games menu, the user needs to select the game ID and its difficulty level before starting the game. This selection information is sent to the bridge program and the corresponding game will be displayed on the big screen in front of the user. All our VR games are in a first-person perspective with virtual right and left arms along with game content. The first-person perspective helps users to focus on target objects in the game and play games as activities of daily life with their arms. At the end of each game level game score, duration and level of assistance are displayed on the screen.

To evaluate the user performance and assess the progress of stroke rehabilitation the data generated during the gameplay cloud be stored either locally or on the cloud to visualize and monitor the improvement over time by clinicians. During the game evaluation test with the exoskeleton robot, we collected exoskeleton orientation data of the shoulder, elbow and wrist joints of the user playing the game both in free mode and assistance mode. The quaternion data was collected for each frame of the game played in Unity3D and converted to Euler angles for visualization purposes. Figs 8 and 9 show the sample shoulder joint data of Pizza Recipe game level 1 of the left arm in free mode and assistance mode respectively.

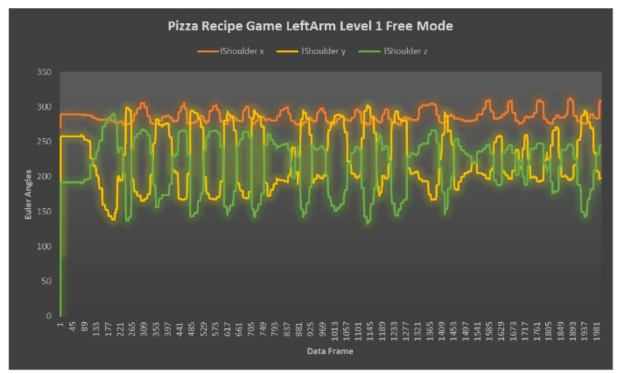

FIGURE 8: SHOULDER JOINT DATA IN FREE MODE

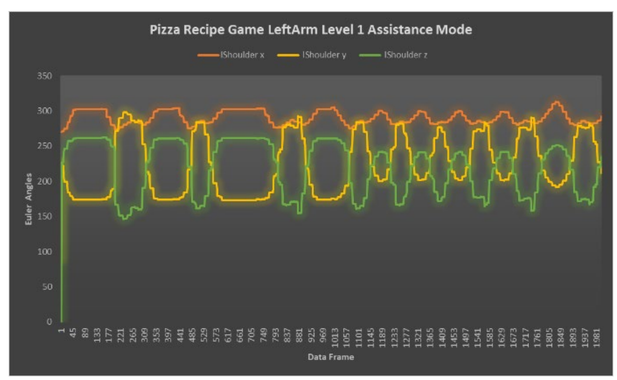

FIGURE 9: SHOULDER JOINT DATA IN ASSISTANCE MODE

These data can be used for conformity purposes so that the data generated by either mode are in a safe workspace. Also, the data provides a day-to-day improvement in the user's upper limb range of motion for clinicians to adjust the safe workspace and further clinical assessment. We also tested the designed VR games for the functional movement of the upper limb to check most of the upper limb rehabilitation movements used in conventional physiotherapy. The types of movements we observed during the testing of VR games are the shoulder abduction/adduction, prono-supination, abduction/adduction, and flexion/extension for wrist movements. Hand moving in a plane that is parallel to the frontal plane and depth is introduced as the level of difficulty increases. The main mechanism of interaction with our VR games is using the exoskeleton robot with minimal supervision in a clinical setting. To further support stroke patients without assistance and who want to extend the therapy in the home environment, we have included the Microsoft Azure Kinect camera as an interactive device as well where they can see their own picture/avatar on the screen. Our main goal is to develop VR games which can create a safe environment that can be changed to suit patient's requirements and can be used for prolonged periods without overburdening them with attachments.

4. CONCLUSION

The main objective of this research was to present design ideas to develop VR games specifically for stroke patients. Particular emphasis was paid to creating non-immersive VR games using upper-limb exoskeleton robots. The VR games we have designed specifically offer stroke rehabilitation with goal-oriented tasks and enriched environments which are repetitive, engaging and offer intense therapy provisions. We believe these games will provide engaging rehabilitation options for upper-limb recovery as compared to off-the-shelf commercial games and will be more accessible to patients being non-immersive. This is a work-in-progress and currently limited to the design and development of VR game content, however, we plan to use this environment to evaluate the games with real stroke patients and develop the game scoring system with standardized assessment protocols for upper limb rehabilitation.

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