Developing a VR training environment for fingers rehabilitation

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Abstract. There are many people worldwide suffering from hand impairment due to stroke. The inabilities to extend the thumb and fingers are the obstacles that face those patients as they cannot successfully grasp and release objects in their daily lives. Therefore, the ability to regain the motion function of fingers of stroke patients becomes an important research topic. Gamification of VR-based rehabilitation system encourages the patients to actively participate in rehabilitation, which could result in the better recovery of their fingers and ideally complement conventional therapy. This research focuses on combining the VIVE headset, haptic feedback Sense Glove, implementing the software development of a Game that provides an engaging VR training environment for fingers rehabilitation. The VR game targets Hemiparesis patients who can train to pick and place virtual objects of different shapes and sizes in a virtual environment. The performance of the patients is analyzed by the system such that the most important assessment parameters turned out to be the velocity and acceleration of their hands. A report is displayed after each level to assess their performance.

Keywords: Hemiperasis, Rehabilitation, Gamification, VR,Sense Glove

1 Introduction

Stroke is one of the main causes of disability for the long term in most countries especially in the elderly population in which stroke incidence is highest. Out of the 795,000 new sufferers of stroke, 26% remain disabled in basic activities of daily living and 50% have reduced mobility due to hemiparesis [1]. In these stroke survivors, the most common loss is the finger extension. Due to the high associated costs with conventional therapy, the duration of sessions is always quite limited. Therefore, safely operated automated rehabilitation systems can be used independently at home and can ideally complete traditional therapy as patients can perform rehabilitation exercises designed by physiatrists and therapists [3].A promising rehabilitation tool that has received increasing attention over the last decades for entertainment and training applications is Virtual Reality (VR) [3]. VR application merged with haptics would increase the efficiency of the rehabilitation of stroke patients. An example of haptic gloves is the Sense Glove which allows the patient to interact with virtual objects inside a virtual space and applies haptic feedback upon interaction. Therefore, correlation should be verified between the Glove and virtual object inside the virtual environment. The use of haptic-based therapy greatly contributes to the loss of mobility. Gamification of VR-based rehabilitation can improve the patient's motivation resulting in an improved overall experience. This can be achieved through a mini VR game designed for hemiparesis patients and can provide easy and low-cost rehabilitation exercises. Those exercises should be repetitive and consistent and provide high levels of engagement [2]. Compared to conventional therapy, VR rehabilitation can monitor and store patients' performance data for evaluation and assessment [3]. The game immerses the patient in tasks guiding the same rehabilitation exercises and movements that a physiotherapy session would offer. The game's design is important to enable the patient to focus on the game. Indications, challenges, pacing, and feedback are crucial to keeping the patient engaged [4]. The patient should perform the task efficiently by overcoming challenges at each level. Gaining this confidence and being familiar with different actions will make it easier for them to execute the tasks and help them concentrate on the game [5].

2 Subjects

Grasping performance is affected by extending all the fingers and thumb. Therefore, investigating the ability to extend all digits is an important study. Hemiparesis patients are those types of the group who suffer from not grasping objects successfully, which causes them a critical weakness in their daily lives when interacting with the environment, people need to be able to appropriately and adequately extend the digits. A study was done on 24 hemiparetic patients at three and 13 weeks post-stroke [6]. The subjects' ability to extend all five digits actively has been tested at each visit. Also, performing a grasping movement with the same hand has been tested. Patients were seated in a chair, and sensors were attached to the fingers and thumb: on the nail of each digit. Subject's affected hand resting in a relaxed position; then they grasp a cylindrical target object, they move at a self-selected pace similar to their daily life. Three trials of grasping movement and digit extension were recorded. The group's characteristics are recruited from the Cognitive rehabilitation group stroke according to the presence of hemiparesis. All subjects took standard stroke rehabilitation - a combination of impairment focused and functional task-focused training. A dynamometer is used to measure the maximum grip strength during a five-finger grip of the affected and unaffected sides. Values were measured in kilograms and presented as a percentage of the unchanged side.The performance test is evaluated based on the movement time, the duration from onset of movement to grasping the object steadily. For each trial, the variable is calculated separately, and the average of the three tests for each subject was used to represent the grasping performance for that patient. According to the previous literature review, some problems need to be tackled for successful hand rehabilitation for hemiparesis patients. Hardware and software requirements should be appropriately integrated to make a VR training environment that could be used for fingers rehabilitation.

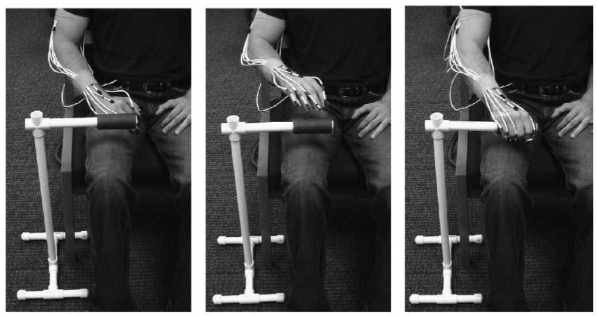


Fig. 1. Grasping Task Steps[6]

3 Solution Design

3.1 Hardware

In this work, HTC VIVE PRO is selected in the research study for different reasons [7]: VIVE headset provides more than 100 degrees field of view compared to other VR headsets and provides good room-scale and excellent update rates. Also, HTC VIVE Tracker can be paired with the virtual reality headset through steam VR which is used to track the position of the hand. The tracker can track the hand accurately through any possible gesture. The system used in this research study is also composed of Sense Glove, a VR controller that provides haptic sensations. The user can feel the density and size of virtual objects inside the virtual environment upon interaction with them through haptic feedback [9]. Sense Glove is chosen in the research study for various reasons: First, hand rehabilitation exercises can be done with it as the glove is full of pressure points. It can replace sensors used to assess a patient's performance instead of using many sensors on the hand. Also, mounting HTC VIVE Tracker is possible for positional tracking of the hands. Furthermore, it provides many feedbacks such as haptic, in which five haptic motors are supplied with a max 0.8G vibration strength located in each fingertip, providing vibrotactile and force feedback. Moreover, Sense Glove provides different rotation sensors for finding the rotational angle of each finger. Therefore, data analysis and grasping performance tests can assess flexion of fingers before and after grasping on hemiparesis patients. This can be achieved by analyzing the full flexion angles of each finger before grasping and after grasping.

Fig. 2. Virtual Reality and Used Glove System [8]

3.2 Software

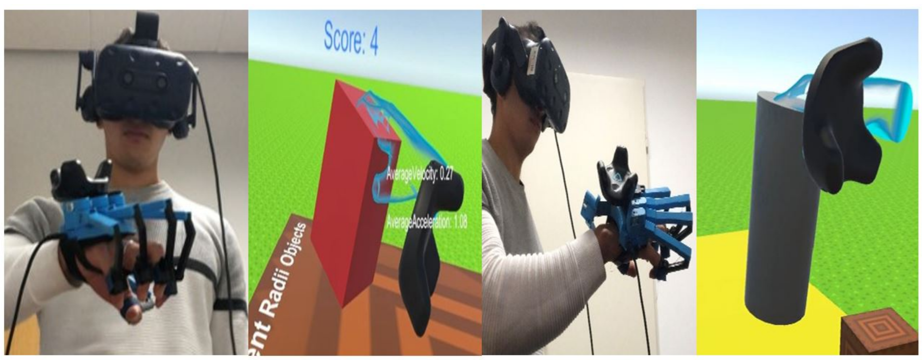
Unity is the platform that has a simple integrating way between the VR headset and the game. Accordingly, communication has to be established between VR headset, tracker, and Sense Glove. Then, an engaging training environment can be designed to achieve successful fingers rehabilitation for hemiparesis patients.

4 Game Development

The game should be realizable in Virtual Reality with the HTC Vive, and it needs to support the execution of the Rehabilitative movement. Unity 3D is one of the most popular platforms for creating virtual environments. One of its advantages is that it is compatible with several VR headsets devices, plug-in, and libraries. Since the target patient is people who suffer from hemiparesis, the room environment game is selected to practice repetitive pick and place exercises in a training environment. Grasping performance is considered throughout the game because when interacting with virtual objects in the virtual environment, the ability to extend all fingers and thumb can be tested by VIVE and Sense Glove system. The VR-based rehabilitation game consists of three levels such that the patients go from one level to the next according to their performance. The patients are asked to pick a certain number of objects from a table and place them in another place in the environment. If the patients succeeded in placing the objects with different sizes and dimensions in the target place within a specific duration they would go to the next level. A set of virtual objects of different radii is presented on a table to assess the ability of the patient to grasp them successfully, as shown in figure 3. Objects and materials properties can be designed to provide rehabilitation tasks; therefore, selecting the more feasibility based on size, shape, and resistance is important. Depending on the skill level of each patient, objects of different sizes are used [10]. Since Sense Glove provides force feedback, a different sensation can be felt based on the virtual object and its material.

4.1 Game Features

A timer is an important feature implemented in the game such that it starts when the patients start interacting with an object in the environment and ends when the patients succeed in the level and can pick and place the objects in the target location in the virtual environment. One of the advantages using timer is that patients' progress can be tracked at each level to assess their performance. Moreover, the game has a running score system to be displayed to the patients when they are playing to track their performance and data analyzing. Whenever they grasp a virtual object and place it in a specific location, they earn a point. Also, they receive audio feedback when they receive a score to increase their motivation. Also, the game has a count-down timer in which the patient can be informed in case of failure in the level.



(a) (b)

Fig. 3. a) First Level b) Second Level of Training

4.2 Data Analysis

Usually, there are sensors attached to the fingers and thumb used to extract the hand's position, velocity, and acceleration. However, a more efficient way is used in the developed system to assess the patient's performance after each level. This is implemented by extracting the full flexion angles from each finger before and after grasping. Then, the angle difference is calculated between being in contact with the object and grasping the object. To achieve calculating the angular velocity and angular acceleration of the fingers, capturing the time when picking and when placing is implemented to know the time between touching and grasping the virtual object. Then the system captures each finger's total flexion angle before and after grasping. After each level, the finger's average velocity and acceleration are displayed as a report to assess the patient's performance, as shown in figure 4. Furthermore, a complete report of all the grasping processes on different locations are analyzed at the end of the game.

5 Experimental Results

The game consists of three different difficulty levels such that more objects are provided in the scene to be picked and placed by the patients in a smaller duration. At level 1 patients pick large objects for workspace range from 0 to 30 degrees and at level 2 patients pick medium sized objects for workspace range from 30 to 70 degrees (Fig 3). At level 3 patient pick tiny objects with workspace range from 0 to 90 degrees (Fig 4). Also the game has a feature of showing the MCP, PIP, DIP angles for each finger individually such that the therapist can analyze the patient's performance throughout the game (Fig 5). A work space has been analyzed when picking and placing objects (Fig 6). After testing the VR game on people, a survey is done to assess the game, and their responses are collected. Questionnaire showed that most of them feel comfortable while using the Sense Glove, and most of them feel comfortable working with the environment.

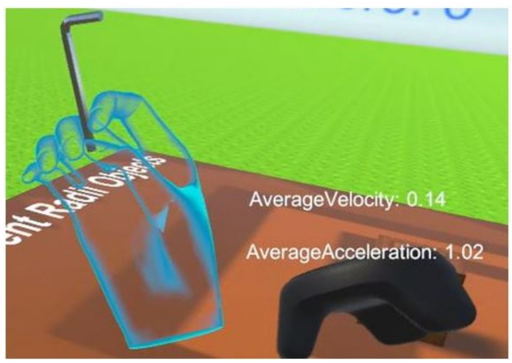


Fig. 4. Third Level of Training

Fig. 5. MCP, PIP, DIP Movement and their measured angles in the game environment

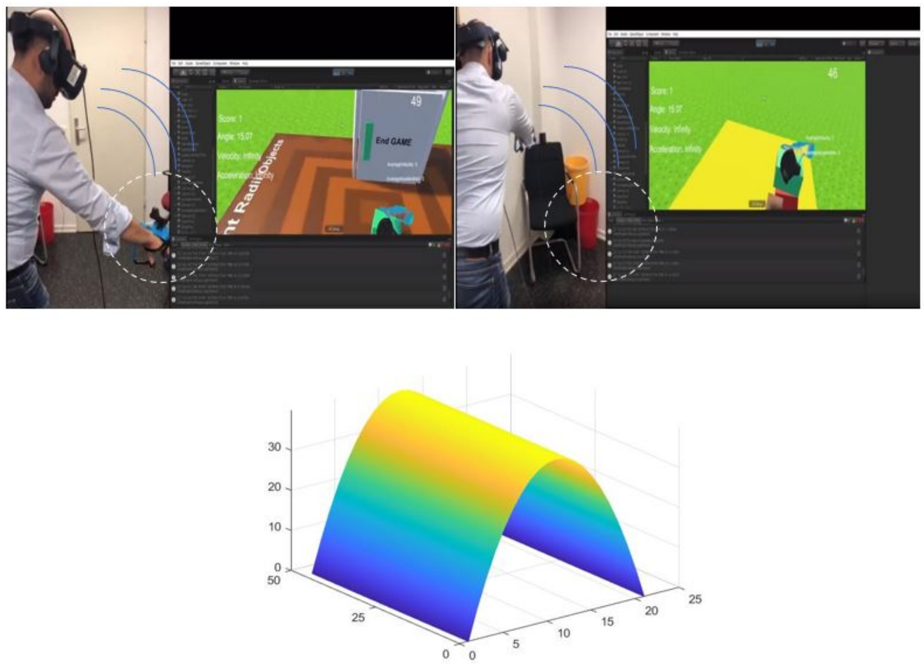


Fig. 6. Workspace provided by hand movement beside the game environment.

6 Conclusion

This work focused on designing and implementing an engaging VR training environment game in Unity3D game engine that can be used for hemiparesis patients for fingers rehabilitation. Various systems use many sensors attached in hand as an approach for assessing the performance of the patients. However, this system follows a different efficient approach in which the sensors built inside the Sense Glove's exoskeleton are used to extract total flexion angle, angular velocity, and angular acceleration of the fingers' movement. To achieve that, communication between Sense Glove, VR headset, and tracker is established, which was challenging and required many configurations to be done in Unity. An evaluation of the performance of the patients is done after each level for their assessment and to see if they are eligible to go to the next difficulty level based on successfully grasping and releasing the objects within a specified time. Grasping performance in this study was evaluated based on each finger's angular velocity and angular acceleration that are recorded throughout the game execution for a continuous report of the patient's progress. Data Analysis was implemented to capture the total flexion angle of each finger in real-time when in point of contact with the object and when grasping the object. Furthermore, capturing the correct time when touching the object and when successfully grasping the object is implemented.

7 Future Work

Testing the game on hemiperasis patients need to be done for assessing their performance and to evaluate them after each level. Furthermore, implementing an environment with high graphics can be the next step to enhance the game.

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