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VR Environment For Upper LIMB Rehabilitation Purposes

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***Abstract*—Stroke is the leading cause of disability worldwide and a great percentage of those who have suffered a stroke are increasing in most countries, which makes it difficult to provide optimal treatment to patients once they return home. Assistive technology solutions can potentially help meet customer demand and also be cost-effective. The aim of this paper is to present the design and development of a virtual reality (VR) system to support the upper limb rehabilitation process of patients with brain injuries. According to the above, the patient in the rehabilitation process can perform various exercises in an interactive way, thus improving the motivation of the patient and reducing the work of the carer. In conclusion, the study presents the technical description of usage scenarios of the implementations of the application in a virtual environment (VE) for people who have suffered a stroke.**

Keywords: Stroke, Virtual Reality, Virtual Environment, Upper Limb, Rehabilitation

I. INTRODUCTION

Stroke is a neurological disease that has been described as the leading cause of disability with significant economic costs during the rehabilitation process (Gbd, 2016 Stroke Collaborators, 2019). Post-stroke patients face a wide range of disabilities from cognitive function to paresis leading to reduced functional capacity and loss of independence. Functional impairment is evident even 5 years after stroke, leading to long-term deficits, especially in activities of daily living (Dhamoon et al., 2009). There is high-quality evidence to support the use of rehabilitation intervention to improve physical function even in patients after severe stroke (McGlinchey et al., 2020). Various recovery rehabilitation techniques have been used. All these techniques have produced substantial beneficial effects. Technological innovations have provided serious advantages in the treatment and rehabilitation of a stroke patient (Patsaki et al., 2022). To improve their quality of life, rehabilitation plays a key role in patients' functionality. Rehabilitation systems should have repetitive, challenging, motivating and intensive exercises to enhance the effectiveness of patients' neural plasticity (Phan et al., 2022).

II. AVAILABLE COMMERCIAL SYSTEMS

Shi and Peng (2018) in their research pointed out that the needs of the user interface for rehabilitation are derived from research and international literature. The functional requirements of the interface are mapped from the needs. The ranking of the functional requirements can be determined by the relative weights of the needs to determine the hardware, software, functions and user interface exercise contents. The House of Quality (HoQ) of the QFD method is used to identify and classify needs, the importance of needs and engineering characteristics. Figure 2 shows a HoQ of the restoration need. The absolute and relative weights of the needs are represented using the following equations (1) and (2):

$$w_j = \sum_{i=1}^{m} a_{ij}\, d_j \quad (1)$$

$$r_j = \frac{w_j}{\sum_{i=1}^{m} w_j} \quad (2)$$

where w_j is the absolute weight of each requirement, a_{ij} is the value of the relationship between recovery needs (RNs) and design requirements (DRs), di is the importance of the i^{th} requirement, and r_j is the relative weight of each design function.

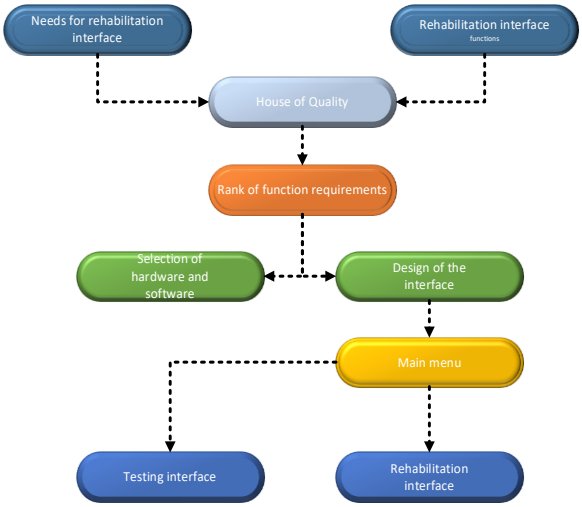

Fig. 1. *User rehabilitation interface*

Correlations	
Positive	+
Negative	−
No Correlation	

Relations	
Strong	●
Medium	○
Low	▽

Direction Improvement	
Maximize	▲
Goal	◇
Minimize	▼

		RNs \ DRs	1 ▲ Installation Manual	2 ▲ VR Software Instructions	3 ◇ Software Content	4 ▲ Device Reliability	5 ▲ Software Reliability	6 ▲ Software Adaptation	7 ◇ Number of Levels	8 ◇ 3D Display	9 ▲ Clinical Assessment	10 ▲ Clinical Evidence	11 ◇ Long Service Time	12 ▼ Reduce the Cost
1	5	Easy to understand	●		○									
2	4	Easy to use		●		○								
3	4	Interesting			●									
4	5	Motivating			●									
5	5	Adequate difficulty					▽	○						
6	3	Graphics quality							▽	○				
7	3	Score tracking							●	○				
8	2	Clinical feedback									●			
9	5	Effectiveness										●		
10	4	Low price											●	○
Absolute weight			25	20	60	12	5	15	18	18	10	25	15	4
Relative score			10	12	37	5	2	6	7	7	4	10	6	2

Fig. 2. *HoQ of rehabilitation needs*

III. VIRTUAL REALITY TECHNOLOGY IN STROKE PATIENTS

Virtual reality (VR) is a simulation technology, which is based on real-time 3D computer graphics, combined with sensor technology, artificial intelligence technology and multimedia to create a series of digital simulation environments (Xiao et al., 2022). Users can interact with objects in the digital environment through interactive devices, which can produce the feeling and experience of being in the real environment (Wu et al., 2019). Kim et al. (2020) in their research found that virtual reality (VR) is a technology that provides interactive environments for patients. Virtual reality (VR) can enhance neuroplasticity and recovery after a stroke by providing more intensive, repetitive and engaging training due to several advantages, including:

- tasks with various levels of difficulty for rehabilitation
- augmented real-time feedback
- more immersive and educational exercises
- more standardized rehabilitation and
- safe simulation of real activities of daily life

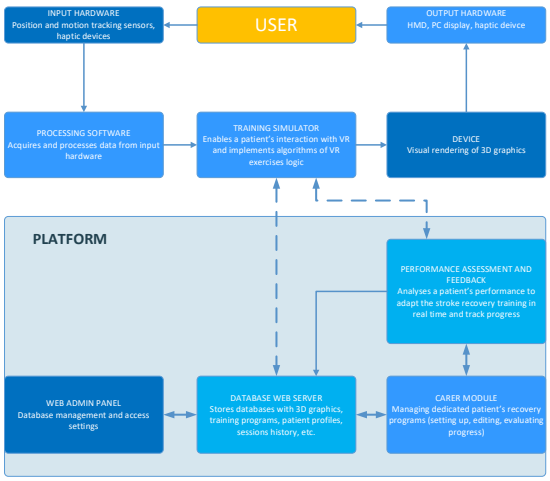

Fig. 3. *VR System Architecture*

The principles of application design are:

1. The content of the application must be logically relevant to attract the interest of patients

2. The app should be goal-oriented and have a purpose where they can motivate patients

3. Positive feedback should be given to continuously encourage patients

4. Recovery techniques should be incorporated into training trials to make the training process more scientific

5. Optional difficulty levels should be designed to apply to different patients and different stages of rehabilitation and

6. Application performance information for patients should be displayed in real-time so that the carer can analyze the rehabilitation status accordingly

Virtual reality (VR) technologies have been used in recent years as a therapeutic tool to improve rehabilitation by enhancing neuronal plasticity and relearning movements (Raffin and Hummel, 2018).

The figure above shows the architecture of the system and its components.

This system is a comprehensive information processing platform that provides carers and doctors with quantified patient education data. The VR environment training system was designed based on the upper extremity rehabilitation device. The overall architecture of the human-computer interaction system is depicted in the Figure 5. The device was designed in such a way that it takes care of collecting the patient's movement information. Motion information is processed in the computer application and displayed on output devices to provide visual feedback to the patient. Therefore, the desktop application is the data interaction center (Zheng et al., 2018).

The presented modeling approach is used as a basis for developing algorithms to create patient-centered treatment pathways. After receiving the required treatments for a patient from the attending carer, the platform creates and suggests adaptive 3D routes within the virtual environment of the application and with different levels of difficulty. Furthermore, the doctor and carer using the platform application map and manage patient's movements and then explain how adaptive pathways and treatment instructions can be created while taking into account the patient's preferences and limitations.

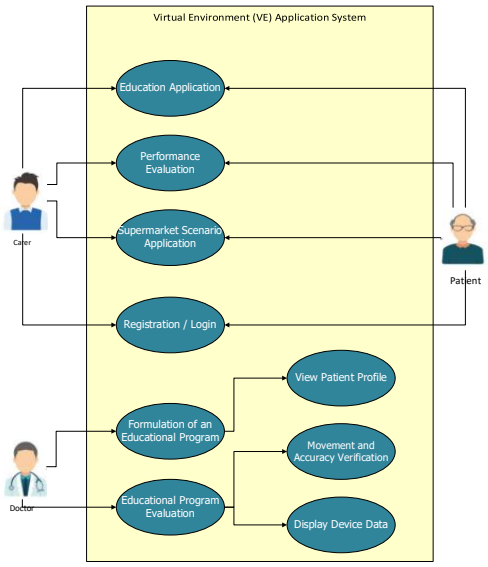

Fig. 4. *Use Case Diagram for Platform System*

The following figure shows the three main categories of participants: patients, doctors and carers. This system helps patients who do not reach an advanced stage or those affected by neurological disorders to regain their lost motor functions. The main functions are focused on patient education (either through exercise using the app using specific rehabilitation movements, by training medical staff (they can observe rehabilitation movements). All users can register when using the app for the first time and each patient will have their profile linked to their carer. Additional carer-targeted functions include configuring a patient's training session (the carer can view a patient's profile and determine which of the system's exercises are appropriate for the patient's condition and severity of disorder, as well as their difficulty levels or level of enhancement for movements) and session evaluation. The design and work in a virtual environment (VE) must be configured under the following conditions:

- To be adaptable and personalized for each patient
- Exercises should be as simple as possible
- They must be easily repeated to ensure that the movement is correct and beneficial to the patient
- Each exercise should have clear goals and limitations

The proposed virtual scenario was designed based on the system architecture. When patients complete the process followed in the script, they can see their score to know the remaining time and performance. This script presents clues to help users complete an activity successfully. However, the system does not force the user to correct their movements. When the user initiates the process in the system, the instructions are first displayed, then the user must press the button on the a-haptic device end-effector to start the application, and then their virtual a-representation appears in the center of the screen. If the user completes the trial, a screen showing the score is displayed. The supermarket scenario was designed as an application. The user moves the hand and operates the device to pick up a product from the shelf.

After that, the patient moves the hand towards the supermarket shelf and presses the button to pick it up. According to the patient's condition, the scenario has three levels. On the first level, the products are on the shelf. In the second, the patient has to pick up the products from the shelf, and finally, in the third level, the patient has to pick up displayed products and bring them to him. Movements relate to the placement of products on the shelves. For virtual reality, a virtual environment (VE) approach and comprehension activity based on a task of selecting products from supermarket shelves was used.

TABLE 1: GENERAL CHARACTERISTICS OF THE VIRTUAL SCENARIOS

Features	Scenario
Objective	Take products from shelves
Virtual representation of the end-effector	Hand
Number of levels	3
Vibrotactile haptic feedback	Contact with Products, Shelves
Clues	Each product is unique

IV. VIRTUAL SCENARIO (SUPERMARKET)

In this research, a task-based virtual reality rehabilitation system was developed, which provides a variety of interactive methods. The system is a flexible, low-cost virtual reality (VR) rehabilitation system, designed to help users manage physical injuries and increase patient performance. It is also divided into a virtual reality training module and a management platform. The training module is developed with the selected device in the form of an "app" to guide users to interact with virtual objects in the scene. In the virtual scene (Supermarket), products on the shelf are randomly selected as the target object. After the products are selected, the patient must control the upper limbs to reach the products and then move them towards him to terminate the application. When it approaches the products, the border color changes from red to blue. As the patient's hand moves away from the product, the color of the outline is red. In this scenario, the introduction of supermarket application elements and immediate feedback on performance seems to be very important as it enhances motivation, encouraging thus a higher number of exercises' repetitions (Mondellini et al., 2019). A Virtual Environment is useful for this purpose, because a repeated exercise, which is simulating with real activities in VR can help stroke patients to be able to work on self-care skills in an environment and scenarios that are usually impossible to replicate in a hospital setting. Although full of potential, the application in the field of treatment and rehabilitation after stroke is quite new and needs further investigation.

V. DISCUSSION - CONCLUSIONS

Virtual reality is an ever-growing technology used to simulate an engaging environment that users experience as comparable to the real world. Therefore, the focus of the research has been on virtual reality (VR)-based rehabilitation systems, as they have been shown to be more effective and engaging than conventional rehabilitation therapy. High-intensity and repetitive task-oriented training is the most effective rehabilitation therapy. The development of a more user-friendly platform using software has started with an application in a virtual environment (supermarket scenario) to rehabilitate patients and measure their performance in real time.

In conclusion, by exercising in a virtual environment (VE), individuals can control their movements and try to reproduce the typical required movements to complete the displayed task in real time in the virtual scene.

VI. Conflict of Interest

There are no conflicts of interest.

VII. Acknowledgements

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