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REGULAR PAPER

A new adaptive VR-based exergame for hand rehabilitation after stroke

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Abstract
The aim of this work is to present an adaptive serious game based on virtual reality (VR) for functional rehabilitation of the hand after stroke. The game focuses on simulating the palmar grasping exercise commonly used in clinical settings. The system's design follows a user-centered approach, involving close collaboration with functional rehabilitation specialists and stroke patients. It uses the Leap motion controller to enable patient interaction in the virtual environment, which was created using the Unity 3D game engine. The system relies on hand gestures involving opening and closing movements to interact with virtual objects. It incorporates parameters to objectively measure participants' performance throughout the game session. These metrics are used to personalize the game's difficulty to each patient's motor skills. To do this, we implemented an approach that dynamically adjusts the difficulty of the exergame according to the patient's performance during the game session. To achieve this, we used an unsupervised machine learning technique known as clustering, in particular using the K-means algorithm. By applying this technique, we were able to classify patients' performance into distinct groups, enabling us to assess their skill level and adapt the difficulty of the game accordingly. To evaluate the system's effectiveness and reliability, we conducted a subjective evaluation involving 11 stroke patients. The standardized System Usability Scale (SUS) questionnaire was used to assess the system's ease of use, while the Intrinsic Motivation Inventory (IMI) was used to evaluate the participants' subjective experience with the system. Evaluations showed that our proposed system is usable and acceptable on a C-level scale, with a good adjective score, and the patients perceived a high intrinsic motivation.

Keywords Functional rehabilitation · Virtual reality (VR) · Exergame · Adaptation · Machine learning

1 Introduction

Serious games in motor rehabilitation offer a promising solution to address issues related to motivation and adherence during therapy sessions [1]. By incorporating gamification techniques [2] into rehabilitation exercises, also known as exergames, the approach aims to make these exercises more engaging and playful. In exergames, patients are required to perform physical activities or exercises that involve moving specific body parts to accomplish the tasks. These games often utilize motion sensors like IMU [3], Vicon [4], OptiTrack [5], Time-of-Flight (ToF) [6], Intel RealSense [7], Microsoft Kinect [8], and Leap Motion [9], to capture the patient's natural movements. This enables the exergames to function as virtual mirrors, providing patients with instant visual feedback and a better perception of their own movements. The integration of gamification into rehabilitation exercises originated from the incorporation of virtual reality (VR) technology in this field. VR has been used in functional rehabilitation for over a decade [10], leading to a new therapeutic approach known as virtual rehabilitation [11]. This approach complements traditional functional rehabilitation, which focuses on using exercise-based rehabilitation to restore motor skills, cognitive abilities, and mental well-being through physical therapy [12]. It particularly addresses motor disability, which is characterized by limited mobility, difficulty performing manual tasks, or impaired movement of body parts. Motor disability can be caused by various factors, including cardiovascular diseases such as stroke, which is the leading cause of motor disability among adults [13]. Following a stroke, one of

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