KeepStep: Interactive Projection-mapping Based Exergames for People with Multiple Sclerosis

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***Abstract*— People with neurological illnesses, such as MS, may benefit from effective training approaches that increase their potential to perform daily tasks. This paper focuses on the concept of adaptive training games for gait rehabilitation in people with multiple sclerosis (PwMS) using individualized exergames. These exergames were influenced by four separate routine physiotherapy exercises. A projection-mapping technique is used to view the planned games on the floor to indicate a safe space for play and to ensure realistic exercise training for PwMS. This is also aided by dynamic difficulty adjustment algorithms, which enable the games to be more adaptable. We anticipate that incorporating adaptability will enable them to provide appropriate challenges, provide an individualized training plan for PwMS, reduce boredom, and minimize therapist involvement. The following phase will be a thorough user analysis.**

Keywords—serious game, exergame, projection-mapping, adaptivity, multiple sclerosis, dynamic difficulty adjustment

I. Introduction

Multiple sclerosis is a neurological disease that affects central nervous system (CNS), resulting in impaired gait, balance, motor weakness, and the inability to perform CNS-controlled tasks [1]. While rehabilitation training cannot cure people with multiple sclerosis (PwMS), it can help them control and develop functional mobility by minimizing their dependency on others and improving their overall quality of life [2]. Traditional physiotherapy and rehabilitation training are often used in the treatment of PwMS [3]. These exercises have certain repetitive movements that should be done for a long period of time. Repetition of recovery exercises is tiresome for a patient. Training that is too easy or too difficult may also make the patient hesitant to continue the exercise. The use of games as a training platform, known as exergame, has been proposed to keep patients motivated during the training process [4,5]. However, game-like preparation is not the only solution. Changes in medical condition should be taken into account in the recovery phase to ensure the required amount of exercise to prescribe at the right time. To put it another way, a flexible and individualized rehabilitation training strategy is required to meet the needs of each patient.

This paper presents several basic training exercises in the form of a game series called "KeepStep[1]," which incorporates adaptability and individualization components. KeepStep was created using a projection-mapping technique. In summary, this work makes the following contributions:

- Developing four different physiotherapy exercises as exergames for gait rehabilitation in PwMS based on their characteristics as determined by a multidisciplinary committee of experts.
- Using a dynamic difficulty adjustment (DDA) technique in exergames to provide adaptability.
- Proposing a projection-mapping technology for viewing the game on the floor to enable realistic exercise training for PwMS.

II. KeepStep

The overview of the system is illustrated in Fig. 1. KeepStep contains four 2D games for gait rehabilitation in PwMS, as shown in Fig. 2.

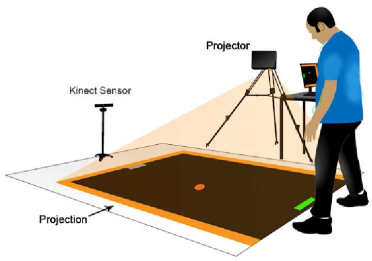

Fig. 1. The general overview of the system

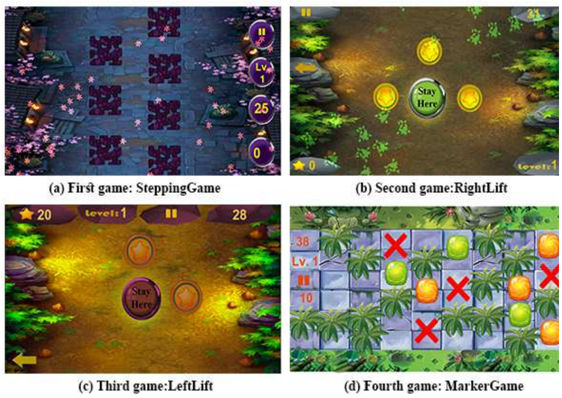

Fig. 2. KeepStep: A game series for gait rehabilitation for PwMS

A. System setup

Our proposed hardware framework involves a video projector installed on top of a tripod and a Microsoft Xbox Kinect V2 as a motion capture kit. The Unity 3D game engine was used to create the exergames. The feedback control system processes data to calculate and render visual signals, which are then projected on the floor by the display system. This system is built on the conceptual framework that we

[1] KeepStep was named the best academic game in the GALA game competition in France in 2020.
https://www.youtube.com/watch?v=Navm2BfuQ7M

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proposed in a prior study [6]. PwMS were instructed to step on the colored markers (targets) that guided them through each game's walk test. Between the beginning and end of the game environment, a fixed distance is maintained. The gained scores and timer are displayed on the floor at the end of each level, and the next level is initiated. The overall workflow of the device is depicted in Fig. 3.

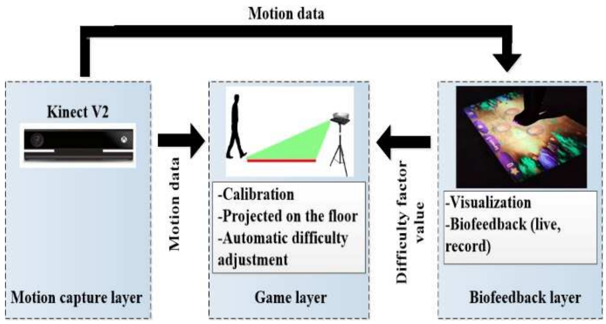

Fig. 3. The overall workflow of the system

B. Projection-mapping

We propose a projection-based augmented reality (AR) technique to provide appropriate gait therapy for PwMS. Through projection-mapping or projection-based AR, augmented information can be precisely observed from a natural field of view [7]. It's worth noting that the suggested platform is non-intrusive and doesn't impose any additional hardware restrictions on users, such as head-mounted or hand-held devices. In PwMS, projection-based AR can help them regain their sense of independence and reduce their fear of falling.

The system architecture consists of four layers. The motion capture layer is the first layer, and it displays the input modalities in their raw form. Gesture recognition, emotion recognition, and image processing patterns are combined in the second layer. In the third layer, you'll find customized video games that help with rehabilitation. This layer is responsible for mapping motion data to game components, calibration, automated difficulty adjustment, and player input. The calibrations portion calculates the corrective model and then transforms it based on the base-plane calibration and the RGB-D sensor calibration. The fourth layer is floor mapping which serves as an output platform, providing biofeedback data as well as the ability to change difficulty.

C. Exergames

Traditional physical therapy exercises influenced our approach to developing the KeepStep. As the foundation of the design, "square-stepping exercise (SSE)," "four square step test (FSST)," and a combination of some physiotherapy exercises were used. A multidisciplinary team comprised of game experts and a physiotherapist, a neurologist, a psychologist helped to identify and choose the necessary physiotherapy instruction. KeepStep's training exercises are focused on the critical skill components for PwMS in gait rehabilitation. These exergames are fundamental training exercises that involve one key skill aspect, such as gait and balance, as well as a combination of numerous implicit cognitive abilities.

KeepStep's games are depicted in Fig. 4, which shows how physiotherapy exercises were converted to projection-mapping-based games. Traditional physiotherapy exercises are shown in Fig. 4 (a, d, e), while their game counterparts are shown in Fig. 4 (b, c, f). Each game is played three times and is divided into two difficulty levels. To earn a score, PwMS must elevate their right or left foot and place it on the designated goals. putting the wrong foot or losing time in each game is a sure way to lose points. Each game's third level begins with a difficulty level that is automatically modified.

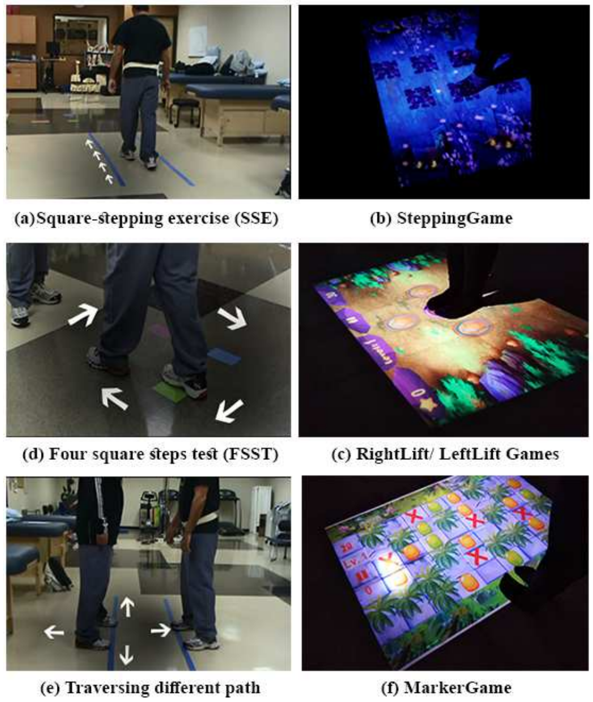

Fig. 4. KeepStep's games (right column), physiotherpay programs (left column)

D. Automatic difficulty level adjustment

A dynamic difficulty adjustment (DDA) technique is proposed for adaptivity. The patient's success and improvement in the exercise can be used to feed the algorithm for automated difficulty adjustments. In general, improved performance during game play is thought to result in better therapy outcomes. To characterize the patient's training progress, PwMS training output data should be collected and compared to the previous training levels. This performance is determined by a combination of variables for all games: the number of scores earned by the patient in the first two levels, task completion time, which indicates how much time is required for the player to complete the game, the number of times the patient has pressed the pause button in the first two levels, and the number of incorrect moves and acquired errors in the first two levels.

PwMS starts the game with an initial level. Based on the patient's performance and progress in each course, the following level's difficulty is determined after two consecutive training levels. If the performance difference between the training levels is insignificant, the patient exercise at an appropriate level, and adaptation will not occur. In the next session, if the patient demonstrates development, the system will automatically provide a level with a greater degree of difficulty.

III. CONCLUSION AND FUTURE WORK

The adaptation of automatic difficulty adjustment is built into all of the KeepStep collection's proposed exergames. As a result, each game has two different difficulty levels, which vary depending on the game parameters. PwMS may continue their exercise at the same difficulty level or progress to a higher level based on their results. We have also tried to construct an appropriate and optimized platform by using a projection-mapping method to view the games on the floor. We expect that including adaptability in the proposed games would enable them to provide appropriate challenges, provide an individualized training plan for PwMS, reduce boredom, and decrease therapist involvement. Therefore, we plan to perform a detailed user analysis to explore the effects of incorporating adaptive difficulty into the KeepStep's exergames. We want to look at the patients' responses to the automated adjustment of difficulty levels. Another next move is to expand our investigation into incorporating adaptivity into our designed exergames in order to determine the games' efficacy on medical parameters over time.

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