Lower Limb Balance Rehabilitation of Post-stroke Patients Using an Evaluating and Training Combined Augmented Reality System

Shuwei Chen*
State Key Laboratory of Virtual Reality Technology and Systems, Beihang University

Ben Hu†
State Key Laboratory of Virtual Reality Technology and Systems, Beihang University
Ningbo University

Yang Gao‡
State Key Laboratory of Virtual Reality Technology and Systems
Research Institute of Frontier Science, Beihang University

Zhiping Liao
Sir Run Run Shaw Hospital, Zhejiang University School of Medicine

Jianhua Li
Sir Run Run Shaw Hospital, Zhejiang University School of Medicine

Aimin Hao
State Key Laboratory of Virtual Reality Technology and Systems
Research Institute of Frontier Science, Beihang University

Abstract

Augmented/virtual reality applications can provide immersive and interactive virtual environment for motor rehabilitation using the collaborative stimulations of multiple sensory channels such as sight, hearing, and movement, enhance the rehabilitation effect through repetitions, feedbacks, and encouragement. In this paper, we propose an evaluating and training integrated application for the rehabilitation of patients with lower limb balance disorder. The AR-based evaluation module visualizes the limits of lower limbs patients' balance abilities and provides quantitative data to their therapists, then rehabilitation therapists can customize personalized VR training games accordingly.

Index Terms: Human computer interaction (HCI)—Interaction paradigms—Mixed / augmented reality; Social and professional topics—Computing / technology policy—Medical information policy—Medical technologies

1 Introduction

Stroke mainly occurs in the elderly, and may cause neurological impairment in patients and affect the limb motor ability, language ability and cognitive ability of stroke survivors [7]. Through timely and appropriate repeated training, the nervous tissue can be partially reconstituted and the motor function of patients will be improved [6]. Clinically, post-stroke patients or patients with lower limb dysfunction mainly use Rehabilitation machinery or exoskeleton [1, 2] to perform various simple repetitive movements under the guidance of therapists to restore the limb motor functions. Difficulty for therapists to evaluate and customize rehabilitation training, lack of incentive and reward mechanism, high price of equipments and the need for experienced therapists are the main weakness of traditional methods. VR, AR technologies have successfully applied to the rehabilitation training of post-stroke patients and patients with brain injury for lower limbs motor function rehabilitation [4, 5, 8]. But in these works, evaluation and training of patients are usually separated, which are closely related in fact. The result of evaluation is very important for rehabilitation training program formulation, and our work takes this into account. Motion capture camera, such like Kinect V2 camera, is a relatively mature and inexpensive virtual reality device, which has great potential in limb rehabilitation. Lange et al. proposed a Kinect-based rehabilitation game for static balance training, which provides quantitative analysis of movements [10]. Besides, they introduced the history and rationale of using VR in clinic and affirmed the potential of VR in the field of rehabilitation [9]. In addition to static balance, many patients have limited leg activity, so dynamic balance is also a key concern in our research. Bobath therapy is a famous neurophysiological therapy for patients with brain injury which was founded by Berta Bobath and has been proved to be effective in early lower limb balance rehabilitation [11].

We propose an augmented reality and virtual reality hybrid system combining with Bobath therapy based on Kinect for lower limb balance rehabilitation of post-stroke patients. Specifically, the salient contributions of this paper include:

- AR-based scientific quantitative evaluation. We provide an AR-based manner to quantitatively evaluate the balance ability of lower limbs. The patient's movement data and balance ability are provided through visual graphics and quantitative data to give the therapists more scientific references.

- VR-based personalized treatment plan. According to the evaluation results, therapists can customize VR-based rehabilitation training programs of different difficulties for the lower limb balance abilities of different patients, and obtain detailed training results and physiological data of patients.

2 System Design

2.1 Hardware and Software

The hardware of our system includes a Kinect V2 camera, a notebook, an A-shaped suspension frame with safety belt (Figure 1). The software includes the application of our system builded by Unity 3D (version 2017.2.0f3, 64 bit) and Kinect for Windows SDK 2.0.

Evaluating (section 2.2) and training (section 2.3) scenes of system are in 3rd person viewpoint with visual information displayed on screen to provide visual feedback for patients. The notebook can be replaced with a large screen and a computer for better visual effects. A-shaped suspension frame with safety belt ensures that patients have enough movement range to protect patients from falling down.

2.2 AR-based Evaluating Scene

We use augmented reality technology to superimpose the patient's bone joint points and virtual soccer balls on the video streaming, which will be displayed on the screen (Figure 2) in real time. There are 9 soccer balls in total, the first 8 of them are in different directions to evaluate the range of movement in patient's coronal plane and the

*e-mail: chenshuwei@buaa.edu.cn
†S. C. and B. H contributed equally and should be regarded as co-first authors.
‡e-mail: gaoyangvr@buaa.edu.cn

Figure 1: A patient is using the system. (1) is Kinect V2 camera, (2) is the screen of notebook, (3) is the safety belt.

9th is located directly in front of the SpineMid point (detected by Kinect) to evaluate the range of movement in forward and backward direction, but the system only displays one ball at the same time. According to Bobath therapy, patient is required to keep fingers crossed and hands clasped, and the thumb of the affected hand is above that of the other one. Then the patient can move the upper limbs and conduct evaluating. The patient is asked to "push" the ball in the corresponding direction (for example, the soccer ball located in upper direction requires the patient's hands to move upward) as far as possible. When the patient does not touch the soccer ball, the edge of the soccer ball will blink in red while a red arrow will be produced instantaneously to indicate the direction from the patient's fist to the soccer ball with instructive prompts. The next soccer ball will appear when patient reaches the limit of movement in current direction. The system will record the range of movement in 9 directions and the evaluating score after the evaluating procedure is over.

Figure 2: Evaluating scene.

2.3 VR-based Training Scene

In this scene, the patient is asked to play as a goalkeeper (Figure 3). The goalkeeper in this scene is an avatar but not chosen specially and the 3rd person viewpoint is adopted. The patient is required to maintain hands clasp same as section 2.2 during training process. At regular intervals, the soccer ball will be shot in the trajectory of a Bézier curve at a constant speed, and the drop position of the ball may be in the eight directions of the patient's coronal plane, which correspond to the first 8 directions of the evaluating scene. The ninth direction in the evaluating scene is not present in training scene. Before the soccer ball being shot, the trajectory of soccer ball will be shown in red, and the direction of drop position will be prompted in screen as well. When the patient saves successfully with hands, cheering sound from the audience will be played to encourage the patient and the next ball will be further away from the patient with a 5% increase in distance between ball's drop position in coronal plane and SpineMid point. We set five levels of difficulty, which contain different ball speed and width of goal. The first 4 levels belong to static standing balance training and the 5th level belongs to dynamic moving balance training, in which patient need to move lower limbs. Position of gravity center and angle of joints will be recorded during training process and can be displayed later. When training is over, the system will display the summary of training including difficulty level, total time and number of successful saves.

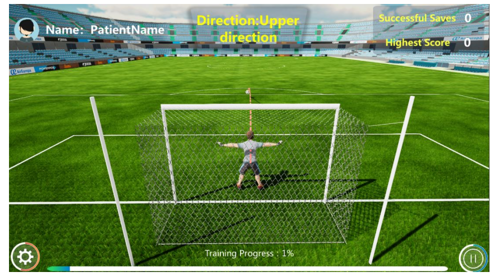

Figure 3: Training scene.

3 Conclusion

We propose an AR/VR-based solution for lower limb balance rehabilitation of post-stroke patients, which combines traditional Bobath therapy and AR/VR to achieve evaluation and rehabilitation training of post-stroke patients. The most important part of our work is quantitative evaluation, and application of evaluation results to customize training. We have conducted an experiment to evaluate the usability in 18 health people using SUS [3] and the result is 68.9 (SD = 9.0). And we received some suggestions from post-stroke participants and therapists, which will help us to modify our system.

In the future, we will conduct control trial to test usability and discomfort symptoms of system in post-stroke patients, and prove the validity of customizable training including the rationality of difficulty level, and accuracy of quantitative evaluation of system.

References

[1] Chapter 7 - exoskeletons for lower-limb rehabilitation. In R. Colombo and V. Sanguineti, eds., *Rehabilitation Robotics*, pp. 89 – 99. Academic Press, 2018.

[2] E. M. Bouhabba, A. A. Shafie, M. R. Khan, and K. Ariffin. Lower-limb rehabilitation robot design. *IOP Conference Series: Materials Science and Engineering*, 53:012038, 2013.

[3] J. Brooke. *SUS: A "quick and dirty" usability scale*. Taylor & Francis, London, UK, 1996.

[4] A. D. Dunsky, Y. H. Hutzler, and P. F. Fishbein. P256: Dual-task training using virtual reality: influence on walking and balance in individuals post-stroke. *European Geriatric Medicine*, 5:S165, 2014.

[5] P. Fishbein, Y. Hutzler, M. Ratmansky, I. Treger, and A. Dunsky. A preliminary study of dual-task training using virtual reality: Influence on walking and balance in chronic poststroke survivors. *Journal of Stroke and Cerebrovascular Diseases*, 28(11), 2019.

[6] L. J. Gonzalez Rothi, N. Musson, J. C. Rosenbek, and C. M. Sapienza. Neuroplasticity and rehabilitation research for speech, language, and swallowing disorders. *J Speech Lang Hear Res*, 51(1):S222, 2008.

[7] K. A. Hossmann. Pathophysiology and therapy of experimental stroke. *Cellular & Molecular Neurobiology*, 26(7-8):1055–1081, 2006.

[8] O. Janeh, O. Fründt, B. Schönwald, A. Gulberti, C. Buhmann, C. Gerloff, F. Steinicke, and M. Pötter-Nerger. Gait training in virtual reality: Short-term effects of different virtual manipulation techniques in parkinson's disease. *Cells*, 8(5):419, 2019.

[9] B. Lange, S. Koenig, C. Y. Chang, E. Mcconnell, E. Suma, M. Bolas, and A. Rizzo. Designing informed game-based rehabilitation tasks leveraging advances in virtual reality. *Disability and Rehabilitation*, 34(22):1863, 2012.

[10] B. Lange, S. Koenig, E. Mcconnell, C. Y. Chang, R. Juang, E. Suma, M. Bolas, and A. Rizzo. Interactive game-based rehabilitation using the microsoft kinect. In *IEEE Virtual Reality*, 2012.

[11] C. Luke, K. Dodd, K. Brock, and S. O. Physiotherapy. Outcomes of the bobath concept on upper limb recovery following stroke. *Clinical Rehabilitation*, 18(8):888–98, 2004.