Leveraging Unencumbered Full Body Control of Animated Virtual Characters for Game-Based Rehabilitation

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Abstract. The use of commercial video games as rehabilitation tools, such as the Nintendo® Wii Fit™, has recently gained much interest in the physical therapy arena. However, physical rehabilitation requires accurate and appropriate tracking and feedback of performance, often not provided by existing commercial console devices or games. This paper describes the development of an application that leverages recent advances in commercial video game technology to provide full-body control of animated virtual characters with low cost markerless tracking. The aim of this research is to develop and evaluate an interactive game-based rehabilitation tool for balance training of adults with neurological injury. This paper outlines the development and evaluation of a game-based rehabilitation tool using the PrimeSense depth sensing technology, designed to elicit specific therapeutic motions when controlling a virtual avatar in pursuit of in-game goals. A sample of nine adults participated in the initial user testing, providing feedback on the hardware and software prototype.

Keywords: video game, balance, stoke, camera tracking

1 Introduction

Stroke incidence, new or recurrent, is approximately 800,000 every year, and as the population ages, this number is expected to rise [1]. The neurological impairments that can result from a stroke, especially impairments in postural control, can affect a person's balance and mobility in everyday activities. Improving postural control is one of the main challenges for stroke rehabilitation. To achieve this, individuals are taught to bear weight through their affected lower extremity, resulting in increased balance and gait velocity, decreased fall risk, and greater participation in activities of daily living. Conventional physical therapy techniques typically use visual biofeedback and force plate systems to encourage weight shift onto the impaired side or limb in order to improve weight shift in sitting, standing and during gait [2,3,4]. However, these techniques provide limited objective measurement of performance and typically lack engaging content to motivate individuals during training.

The use of commercial video games as rehabilitation tools, such as the Nintendo® Wii Fit™, has recently gained much interest in the physical therapy arena. While anecdotal evidence suggests that games have the potential to be powerful motivators for engaging in physical activity, limited published research exists on the feasibility and effectiveness of leveraging the motion sensing capabilities of commercially available gaming systems for rehabilitation [5,6,7,8,9]. Initial case studies have demonstrated that the use of video games has some promise for balance rehabilitation following stroke and spinal cord injury [7,8,9,10]. However, currently available commercial games may not be suitable for the controlled, focused exercise required for therapy. Usability studies have found that some commercially available games provide negative auditory and visual feedback during therapy tasks [6,11]. These observations demonstrate the importance designing games specifically for rehabilitation, a design approach that has been investigated by several recent researchers [11,12,13]. However, the limitations of the commercial video game motion sensing technology have been a challenge to achieving this goal. Motion tracking controllers such as the Nintendo® Wiimote are not sensitive enough to accurately measure performance in all components of balance. Additionally, users can figure out how to "cheat" inaccurate trackers by performing minimal movement (e.g. wrist twisting a Wiimote instead of a full arm swing). Physical rehabilitation requires accurate and appropriate tracking and feedback of performance. As such, we are developing applications that leverage recent advances in commercial video game technology to provide full-body control of animated virtual characters. A key component of our approach is the use of newly available low-cost depth sensing technology from PrimeSense, the company that developed the sensor hardware in the popular Microsoft® Kinect. This technology, along with software from OpenNI, provides markerless full-body tracking on a conventional PC using a single plug-and-play USB sensor. Not only does this approach provide a fully articulated skeleton that describes the user's body pose, but it does so without encumbering the user with tracking devices or markers. This appears to provide more natural and intuitive interaction, without having to alter natural motor movements to accommodate the tracking hardware. The depth sensing camera allows the user to puppet a virtual character on screen that directly represents their movements and poses in the real world. This system approach enables a game-based rehabilitation tool that is tailored to individual therapy goals. This application is being developed and refined through the process of user-centered design, incorporating feedback from key stakeholders (clinicians, patient groups and care takers) and undergoing iterative feedback and refinement phases.

2 Method

The aim of this research is to develop and assess an interactive game-based rehabilitation tool for balance training of adults with neurological injury. We developed a game-based rehabilitation task designed to elicit specific therapeutic motions when controlling a virtual avatar in pursuit of the in-game goal.

2.1 Hardware

Full-body interaction with the game was provided by the PrimeSense Reference Design, a USB plug-and-play device that uses an IR projector along with standard RGB and infrared CMOS image sensors (Figure 1). To construct a depth map, the sensor uses a proprietary algorithm to resolve the pattern produced by projecting coded infrared light onto the scene geometry. This system has a field-of-view of 58 degrees horizontal and 45 degrees vertical, and generated depth maps with a resolution of 640x480 at 30 frames per second.

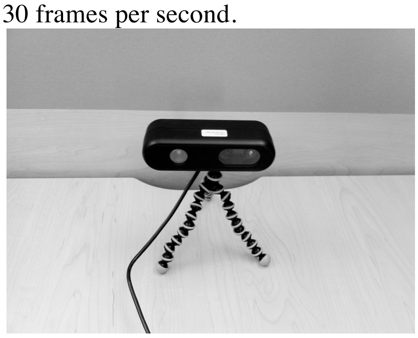

Fig. 1. PrimeSense Reference Design USB plug-and-play device

2.2 Software Architecture

The software components of the sensing package are the OpenNI and NITE frameworks, which provide user identification, scene segmentation, and skeleton tracking. To create the game, we used the Unity3 game engine along with an OpenNI wrapper developed by PrimeSense to integrate these frameworks with the game engine. The engine provides a C# API and flexible editor which allows for rapid development of games. This rapid development cycle enables faster iteration of game mechanics and ultimately results in more specificity for tailoring games to address patient's individual disabilities.

2.3 Game Overview

The game world involves a precious jewel mine where the player assumes the role of a miner who rides a railroad cart down a mine shaft and gathers jewels from the shaft walls. The shaft is uniformly cylindrical with eight jewels arranged in a ring with the player's avatar centered in the middle of the screen (Figure 2). In order for the player to successfully gather all the jewels they must reach out from the center of the screen and touch each jewel individually with their hand.

Fig. 2. The game is set in a jewel mine. The player's character is situated in the center of the mine shaft with eight gems placed around them in a ring

2.4 Calibration

The game begins with a calibration step which maps the range of motion of the player's upper limbs. After striking a default calibration pose for a few seconds (Figure 3) the player's skeleton is captured and tracked without any attachment of devices or markers.

Fig. 3. User calibration step: The player must strike a default pose and the player's upper torso, arms, hands and head are represented on the screen

The supporting OpenNI software recognizes when a human figure enters the frame and sends joint position data from the PrimeSense camera to the game. This position data is then transformed into joint orientations with simple trigonometry algorithms.

The player's upper torso, arms, hands and head are represented on-screen by an abstract avatar made up of white cylinders for the arms, chest and hands and a sphere for the head (Figure 3). The length of the cylinders for the chest and arms are scaled to match each player's specific anatomy.

To map the individual player's range of motion, the player moves their arms as far as possible in 3D space forward and outward in an arc over eight radiating lines. This step should be guided by a clinician to encourage movements that are appropriate for the player and specific therapy goals. As the player holds their hand at the intersecting point of each line a jewel is placed at the point of intersection (Figure 4). Upon completing the placement of each jewel, the positions are saved and loaded into the game itself.

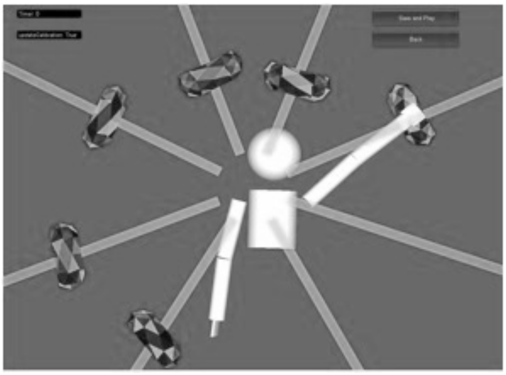

Fig. 4. Calibration step: to map the individual player's range of motion, the player moves their arms as far as possible outward in an arc over eight radiating lines

2.5 Gameplay

In the game, all eight jewels are present and visible in a series of rings that extend as the player moves through the mine shaft. Individual jewels glow to indicate when they can be gathered. The order in which the jewels glow is controlled by three different pre-defined patterns that the clinician can select before a session begins: Sequential pattern, Simon pattern or Sam pattern. During the Sequential pattern, jewels light up one by one. The player's goal is to collect the gems as they light up. During the Simon pattern, the jewels light up in the classic "Simon" game pattern and the player must remember the sequence in which the jewels light up and touch them in that order. The Sam pattern was designed to be a modified "Simon" pattern where the recall task is removed and the jewels remain lit until the player collects them. The Sequential and Sam patterns each have two difficulty settings.

2.5 Avatar Representation

Before starting the game the clinician is given the option of displaying the player’s avatar as either a full torso with arms and head or simply displaying the hands (Figures 5a and 5b). This avatar representation allows the clinician to control how much feedback the player receives about their body position during the game. The full upper torso is tracked within both representation settings, however the hands only representation provides visual representation of the hand points of the skeleton.

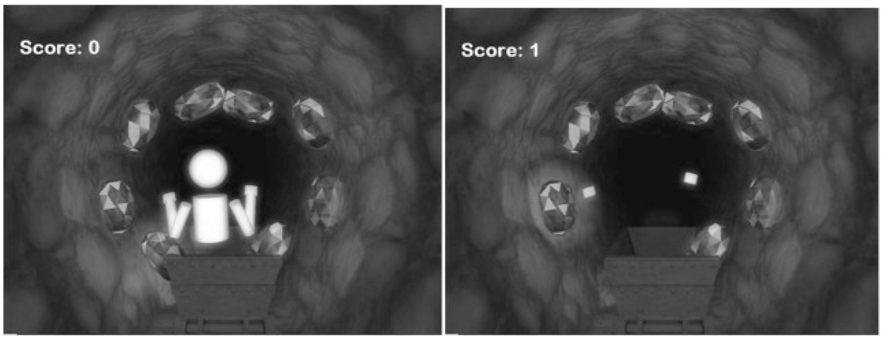

Fig. 5. Avatar representation: The game can be played with a upper torso skeleton avatar (a) or with only the player’s hands represented on the screen as two squares (b)

2.6 Data Recording

The player’s range of motion calibration settings are saved as a player profile and can be loaded in subsequent sessions. Additionally, the duration of time it takes patients to complete each jewel ring task and the total time it takes to complete the game are recorded and reported (Figure 6).

--- Calibration Result X Y Z ---

Chest position: 1 0.2484931 1

Jewel position	X co-ord	Yco-ord	Zco-ord
1	0.3943838	-0.6179914	0.253845
2	0.7456294	-0.29836	0.2684347
3	0.5976502	0.3058621	0.2703076
4	0.1498267	0.3934466	0.2028612
5	-0.159591	0.3960093	0.1996299
6	-0.6877971	0.2773086	0.3805319
7	-0.7845222	-0.2559808	0.5556321
8	-0.3397403	-0.5998452	0.3483063

--- Performance Result ---

					Time to complete			
DATE	TIME	GAME pattern	Hand/fullbody	Total Jewels	Total time	Ring 1	Ring 2	Ring 3
1/31/11	1:56:33 PM	Sequential	HandOnly	16	41.50s	15.40s	12.54s	-
1/31/11	1:57:54 PM	Sequential	Skeleton	16	42.15s	11.81s	16.41s	-
1/31/11	1:59:04 PM	Simon	HandOnly	8	41.30s	4.33s	6.60s	9.77s
1/31/11	2:00:15 PM	Simon	Skeleton	8	43.85s	5.40s	8.58s	9.65s
1/31/11	2:01:54 PM	No_Pattern	HandOnly	24	58.82s	15.45s	10.34s	12.44s
1/31/11	2:03:11 PM	No_Pattern	Skeleton	24	48.98s	8.30s	11.64s	8.44s

Fig. 6. Data recorded from game includes player profile and time to complete the in-game tasks

2.7 User Testing

To evaluate the usability of the rehabilitation game, participants receiving balance training following stroke were recruited from two Rehabilitation Clinics in the Los Angeles area. Participants were asked to perform two game-based tasks, which were randomized for each participant. The two game-based tasks differed in presentation of participant's character on the screen: upper torso skeleton and hands only view. The Sequential pattern was used for both tasks. The researchers observed participants playing the game, providing assistance when needed. Following the interaction, the participant was asked to complete a structured interview about their experience. Clinicians attending the user testing session with a participant were also asked to provide feedback. Game performance, researcher observations and player feedback were analyzed to investigate how these game design criteria influence the performance of tasks that are relevant for rehabilitation.

3 Results

To date, a sample of nine participants (four females and five males), aged 52-78 years have been recruited in the study. Participants, receiving therapy following stroke (six months to seven years post stroke), were able to sit or stand independently or with light assistance. Three participants had previous experience playing video games. Of those three participants, only one owned and used a Nintendo® Wii™ and Nintendo® Wii Fit™ in their home.

Four participants played the game in their wheelchair, while five participants played the game in standing. In standing, three participants required stand-by assistance and two participants required light-moderate assistance.

3.1 Calibration

All of the participants had difficulty performing the calibration pose. Two of the nine participants could not complete the calibration step, and therefore were unable to play the game and could not complete the rest of the testing session. Limitations in range of motion of the impaired upper limb prevented these participants from being able to perform and maintain the required position. The final seven participants required assistance from a clinician to provide active assisted or passive shoulder flexion, abduction and external rotation of the impaired upper limb in order to perform and maintain the calibration pose.

3.2 Game Play Observations

Participants, both in a wheelchair and in standing, were able to complete the game-based tasks with assistance where required. During game play, participants tended to need more instruction initially at the start of the game. However, following the completion of one to three sets of the jewels, participants appeared to gain sufficient understanding of the task to perform without instructions. Five of the participants had particular difficulty with perception of the depth of the jewels within the 3D space.

3.3 User Feedback

The structured interview questions provided qualitative data about user perceptions of the technology, motivation to use the technology and specific feedback on potential changes to improve the existing system. Participants provided the research team with suggestions for improving the instructions for the game and game play elements (such as scoring and sound effects).

Overall, participants reported the game to be challenging and fun. Specific comments related to level of challenge and enjoyment were:

"I think it was more exciting than working muscles just in the gym"

"You really made me work hard!"

"I enjoyed it but it made me work really hard to get all those gems"

"I felt like I was really slow at first but once I got the hang of it I had fun"

"It was good. I want to play it again."

"When I was collecting the gems I wasn't thinking about how hard I was working"

Each of the seven participants chose the skeleton avatar in preference over the hands-only avatar. Participants stated that seeing the full upper body avatar gave them more information about how they were moving and helped them to collect the jewels.

When asked to describe how the game compares to current therapy activities, four participants responded that the game was similar to activities they are currently asked to perform in therapy sessions. Five out of the seven participants that were able to play the game stated that they would like to play the game again and could see themselves playing the game as part of their regular therapy once it is completed.

3.4 Clinician Feedback

A sample of four clinicians consented to provide feedback on the system. Overall, the clinicians stated they were excited about the use of this type of technology within the clinical setting. One clinician stated he had been investigating commercially available games for use with his patients but had found many of the game-based tasks to be too difficult. He stated that the concept of calibrating the system to an individual user and having control over the game-based task was an important feature in the current prototype. Furthermore, the option to change the avatar view from skeleton to hand only views, providing less feedback, therefore increasing the level of challenge for the patient appealed to the clinicians.

4 Discussion

The release of the PrimeSense 3D depth sensing technology provides a low-cost option to capture users' full body movement in 3D space for interaction within game activities without the need for the user to hold an interface device. Whilst this provides developers, researchers and clinicians with access to low-cost tracking technologies that can be more easily implemented within tailor made software programs, accessibility of the system is still limited to people who can actively or passively perform the calibration pose. At this point in time, people with disabilities that limit them from being able to perform the calibration pose, cannot interact with the system.

Calibration is an important piece of tailoring game-based applications for individuals with varying levels of ability. The current OpenNI software technology will track the user only once a calibration pose has been performed. The calibration pose requires the user to stand or sit facing the camera, place the arms out to the side with the shoulder in external rotation and at 90 degrees abduction and the elbow at 90 degrees of flexion (Figure 2a). The importance of user-centered design is highlighted when issues such as calibration are exposed earlier in the development process to allow for changes that will make the system more accessible to the key stakeholders that will be using the system.

Despite difficulties with calibration, initial user feedback supported the use of game-based rehabilitation and provided a range of suggestions for system improvement. The suggestions and comments are currently being themed and will be discussed, evaluated and prioritized by the research and development team.

Feedback from clinicians was supportive of the development of a flexible system that provides the option to tailor the game-based task to the user. Clinicians liked the option to change the avatar view from skeleton to hand only views. Changing the appearance of the avatar, whilst still tracking the skeleton, allows the clinician to remove visual feedback provided to the patient. Removing this external feedback, encourages the patient to rely on internal sensory-perceptual information to control their movement [14]. Providing less visual feedback about the player's movement increases the level of difficulty and this was supported in the participant's unanimous choice of the skeleton avatar as the easiest to understand and use. However, the use of the hands only avatar representation is important progression in therapy guided by motor learning principles [14].

The research team have been developing a Flexible Action and Articulated Skeleton Toolkit (FAAST) with a goal to make a general purpose software environment that enables many applications to quickly be modified to use depth sensing technolgoies (http://projects.ict.usc.edu/mxr/faast/).

Some of our early work and updated videos can be viewed at http://www.youtube.com/user/AlbertSkipRizzo#p/u/5/geyIvG4uKxY

5 Conclusions

This preliminary research supports the development of a novel and flexible game-based rehabilitation system for balance training. The initial user testing provided insight into key features that need modification or improvement to develop an accessible and user friendly rehabilitation tool with an emphasis on custom calibration and kinematic modeling.

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References

1. American Heart Association. Heart disease and stroke statistics 2010 update: A report from the American Heart Association. Circulation. 121, e46--e215 (2010)
2. Geiger, R.A., Allen, J.B., O'Keefe, J.: Balance and Mobility Following Stroke: Effects of Physical Therapy Interventions With and Without Biofeedback/Forceplate Training. Phys Ther. 81(4), 995--1005 (2001)
3. Walker, C., Brouwer, BJ., Culham, E.G. Use of Visual Feedback in Retraining Balance Following Acute Stroke. Phys Ther. 80(9), 886--895 (2000)
4. Yavuzer, G., Eser, F., Karakus, D., Karaoglan, B., Stam, HJ. The Effects of Balance Training on Gait Late After Stroke: A Randomized Controlled Trial. Clin Rehabil. 20(11), 960--969 (2006)
5. Gargin, K., Pizzi, L. Wii-HAB: Using the Wii Video Game System As An Occupational Therapy Intervention With Patients in the Hospital Setting. Health Policy Newsletter. March (2010)
6. Lange, B.S., Flynn, S.M., Rizzo, A.A. Initial Usability Assessment of Off-the-shelf Video Game Consoles for Clinical Game-based Motor Rehabilitation. Phys Ther Rev. 14(5), 355--363 (2009)
7. Deutsch, J.E., Robbins, D., Morrison, J., Bowlby, P.G. Wii-based Compared to Standard of Care Balance and Mobility Rehabilitation for Two Individuals Post-stroke. Virtual Rehabilitation International Conference. June 29- July 2, 2009, Hafia, Israel
8. Sugarman, H., Weisel-Eichler, A., Burstin, A., Brown, R. Use of the Wii Fit System For the Treatment of Balance Problems in the Elderly: A Feasibility Study. Virtual Rehabilitation International Conference. June 29- July 2, 2009, Hafia, Israel
9. Nitz, J.C., Kuys, S., Isles, R., Fu, S. Is The Wii Fit A New-generation Tool for Improving Balance, Health and Well-being? A Pilot Study. Climacteric. pp1—6 (2009)
10. Flynn, S.M., Palma, P., Bender, A. Feasibility of Using the Sony Playstation 2 Gaming Platform for An Individual Poststroke: A Case Report. Journal of Neurologic Physical Therapy. 31(4), 180--189 (2007)
11. Lange, B.S., Flynn, S.M., Chang, C., Ahmed, A., Geng, Y., Utsav, K., Xu, M., Seok, D., Cheng, S., Rizzo, A.A. Development of An Interactive Rehabilitation Game Using the Nintendo® Wii Fit™ Balance Board for People With Neurological Injury. ICDVRAT Proceedings, August 31--September 2, Chile (2010)
12. Gil-Gómez, J.A., Lozano, J.A., Alcañiz, M. Nintendo Wii Balance Board for Balance Disorders. Virtual Rehabilitation International Conference, June 29-- July 2, Hafia, Israel (2009)
13. Billis, A.S., Konstantinidis, E.I., Mouzakidis, C., Tsolaki, M.N., Pappas, C., Bamidis, P.D. A Game-like Interface For Training Senior's Dynamic Balance and Coordination. Medicon IFMBE Proceedings. 29, 691--694 (2010)
14. Van Vliet, P.M., Wulf, G. Extrinsic Feedback for Motor Learning After Stroke: What is the Evidence? Disability and Rehabilitation. 28 (13-14), 831--840 (2006)