The Design of an Interactive Stroke Rehabilitation Gaming System

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Abstract. There is a compelling need to create an alternative and affordable home based therapy system founded on sound rehabilitative principles, that is readily available, engaging and motivational, and can be remotely monitored by therapists. In the past two years, stroke related medical costs have increased 20%, while the number of clinical treatment sessions have declined. The purpose of this study was to develop an affordable interactive stroke rehabilitation gaming experience based on therapeutic fundamentals that can easily be used in the clinical setting or the home environment.

Keywords: rehabilitation, gaming, health, upper extremity.

1 Introduction

Cerebrovascular accidents (strokes) are a major cause of disability and the third leading cause of death in the United States, with 780,000 new and recurrent strokes occurring every year. In the past two years, stroke-related medical costs have increased 20% [1] while the numbers of clinical treatment sessions have declined. Accordingly, there is a need to create a home-based stroke rehabilitation system that is affordable, predicated upon sound rehabilitative fundamentals while remaining compatible with interests and activities that promote compliance. Merging existing therapy methods with an evolving notion of "gaming" from the realm of entertainment toward more serious endeavors has the potential to produce a unique rehabilitation learning experience for stroke survivors.

1.1 Approaches to Stroke Rehabilitation

Traditional customary care involves time intensive treatment from an occupational therapist. The rehabilitation strategy depends largely on the goals of the stroke survivor and their current capabilities with regards to range of motion, strength and functional

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status. This form of rehabilitation often involves performing repetitive movements, which have been shown to induce motor learning and therefore improve the movement behaviour of the stroke survivor [2-3]. Several alternative rehabilitation methods have been proposed. Constrained Induced Movement Therapy (CIMT) involves having the stroke survivor wear a mitten on the healthy arm for long periods of time, thereby restricting movement of the healthy arm and forcing the use of the affected arm [4]. CIMT is only useful for a sub-group of the stroke population because of the mental and psychological requirements in having self-discipline to stick with the program. Another alternative looks at ways to accomplish rehabilitation by using robotics. The notion here being that robots can perform and measure repetitive movement without growing tired, thereby allowing the occupational therapist the ability to work with multiple stroke survivors at once. The draw back to this is that robotic solutions are not cost effective for small business nor is it feasible for the home environment. Robotics also requires some level of skill to operate the robot appropriately. Current paradigms in robotic motor learning involve simple reaching pattern tasks that are not very engaging or motivational, however have been shown to significantly improve the movement behaviour of a stroke survivor [5-7].

Studies have shown that the Wii can have a beneficial health impact on stroke survivors [8-9]. However, current consumer video games for consoles, such as the Wii, require precise dexterous movements and are designed around completing game activities under extreme time pressure; two features that are inappropriate for stroke rehabilitation therapy. Several systems have been designed specifically for stroke intervention, such as the TheraJoy, T-WREX or the RUPERT [10-13]. However, such systems assume that the stroke survivor is able to both grasp and manipulate a joystick or don an exoskeletal orthosis/robot. These systems also do not contain interactive motivational gaming experiences to keep patients engaged, and are too expensive and complex for home use.

1.2 Benefits of gaming

There is mounting evidence suggesting that playing video games produces gains in certain physical and cognitive abilities. Previous studies using video games as the primary intervention have found improvements in reaction time, short-term and long-term memory, attention [14], and spatial ability. While the majority of this research has been conducted with adolescent and young adults, there are a few studies that have also explored video games as an intervention for stroke survivors. Gains in prose recall were found in a sample of stroke patients with memory impairment after interaction with memory games [15]. Other investigators have speculated that playing videogames may actually stimulate neurons common to the visuomotor pathways that lead to improved reaction time [16]. While prior investigations have explored the design of gaming systems focused on memory and prose recall for the stroke population, few efforts have attempted to encode specific rehabilitative movements as part of an interactive gaming experience.

1.3 Purpose

The primary goal of this research effort was to create a compelling and fun game/experience that users would enjoy playing and that would also improve the

mobility and dexterity of their stroke-affected arm. Through the intersection of Rehabilitation Medicine, Computer Science and Engineering, a proof-of-concept investigation of an innovative home-based stroke rehabilitation technology was developed that encoded a computer video game experience with a limited number of specific rehabilitation movements that were based on sound rehabilitative principles.

2 System Hardware Architecture

Stroke survivors are often not able to grasp and manipulate objects with their affected hand. Therefore careful consideration was given to the type of input device and its attachment to the arm.

2.1 Input Devices

The stroke rehabilitation game utilizes a Wii Remote motion tracking controller from Nintendo's Wii game console. The Wii Remote includes an infrared (IR) camera that can be used to track the position and orientation of a set of IR beacons. A prototype version of the stroke rehab game uses two IR beacons rigidly attached to the player's stroke affected arm and tracked by a ceiling mounted Wii Remote's IR camera. This configuration allows accurate 2D position tracking of the player's forearm.

The raw, 2D forearm tracking data is filtered using a spring-damper function, the output of which is used as the end-effector position of a simple inverse-kinematic (IK) model of a human arm, including a shoulder joint and an elbow joint. The internal IK arm modeling allows reasonably accurate arm motion tracking in a horizontal plane extending from the player's chest forward and perpendicular to the floor.

2.2 System Display

The development and testing of the system was done on a personal computer. This allowed us to create a system that has a more powerful Central Processing Unit (CPU) and Graphics Processing Unit (GPU) than the Nintendo Wii console. A future design goal for the game display would be to incorporate a low cost portable console that could connect directly to a television.

3 System Software Architecture

The prototype stroke rehabilitation game was developed in the Unity 3D game engine. Unity provides a rapid game prototyping and development environment and is based on the Mono .NET software framework. Unity supports cross-platform game development and supports most of the Mono/.NET framework capabilities, including Unix sockets inter-application communication. Unity's Mono/.NET architecture was used to develop a custom Unix sockets client/server interface to communicate with a Nintendo Wii remote which is used as the primary game input device. A separate Wii remote server application was developed to communicate with and receive Wii remote telemetry data such as IR beacon spatial locations. The Wii remote server communicates with the Unity game via a Mono/.Net sockets client object inside the

game. During game play, the Wii remote continuously reports IR position tracking data to the game application. Wii remote accelerometer data and button states are also reported and this data may be utilized in future versions of the stroke rehabilitation game.

3.1 System Operation

The stroke rehabilitation game includes most of Peggle's game mechanics and behaviors, but is augmented to facilitate stroke-affected arm motions and exercises. Whereas Peggle uses a mouse or keyboard to aim and fire balls, the stroke rehab game utilizes a Wii Remote motion tracking controller from Nintendo's Wii game console.

3.2 System Content

A number of video game styles and genres were considered as prototypes for a suitable rehabilitation game. Ultimately, the popular casual game Peggle was chosen as a model for the stroke rehabilitation game (Figure 1). This greatly simplified and sped up the graphical and game play design phases and allowed more time and resources to be spent on augmenting and adapting the game to support stroke rehabilitation in the form of encouraging specific arm motions and exercises.

Peggle itself is loosely based on older, mechanical games such as pinball and pachinko (a Japanese version of pinball). Peggle consists of a grid of pegs and other targets, all of which are assigned point values, and allows the user to sequentially fire balls, much as with pinball and pachinko machines, onto the play field with the goal of hitting, and thereby destroying, as many pegs as possible. The player's score accumulates as pegs are hit and destroyed. In the original Peggle game, the player can aim a ball-firing canon. Skill and strategy are required to clear the peg field efficiently, but chance also comes into play as a physics engine controls the ball motion and ball behavior is difficult to predict after the first few ball-peg collision interactions.

A variety of game behaviors can be triggered and controlled via large and small arm motions in the tracking plane previously described. The game control motions were chosen to mimic currently used stroke rehabilitation arm exercises and include precision aiming of the ball canon, positioning of a catch bucket at the bottom of the peg field (used to catch balls as they fall, and score extra points and turns), increasing a point-multiplier "power" value prior to firing a ball. Each such control regime can be tailored, even during a game session, to encourage specific arm motions and exercises such as maximizing affected arm range of motion, training arm motions for precision, training arm motions for stability and minimizing tremor.

4 System Design and Usability

Stroke survivors tend to have limited range of motion, slow reaction time and impaired cognitive skills. Therefore this game had to be based somewhat on chance, yet still be physically challenging and motivational for the individual to continue.

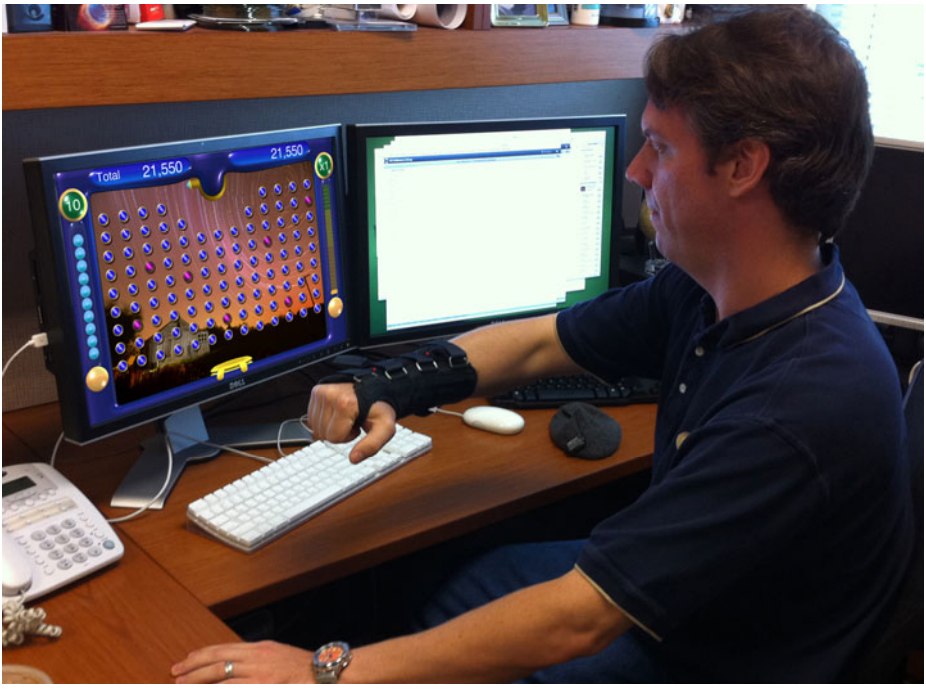

Fig. 1. The prototype of the rehabilitation gaming system

4.1 Design Criteria

Knowledge gathering exercises were conducted with two experts in the field of stroke rehabilitation to ensure that the type of arm motions and exercises to be encoded into the game could lead to improvements in stroke survivors. In designing the game, a number of design criteria were developed which would facilitate stroke rehabilitation movements and exercises yet still be fun and compelling. The game rules and mechanics should be simple and easily understood with the right balance of skill, chance and strategy: enough skill required to facilitate rehabilitating motions and enough chance and strategy required to create compelling game play and motivate the player to play more often and for longer periods of time.

To create an effective and enjoyable game, this initiative followed an iterative game design process. A small set of rehabilitative movements were to be encoded in the game and used for rehabilitation (informed by metrics such as the WolfMotor Function Test [17].

The game design required additional considerations due to the uniqueness and limitations of the target users and to the functional requirements for successful physical rehabilitation. In particular, to achieve true physical gains the players would need to spend significant time in the environment; thus the intervention must be engaging and playable for adults of any age. A game that is boring and tedious or an interface that is too physically strenuous would be unacceptable. A game mechanic that is too easily mastered or that is too difficult can cause player frustration and nullify benefits of the system.

Designing an environment that leads to a feeling of engagement, immersion and "oneness" with the system is more of an art than a science. However, extensive research exists in the area of computer interfaces for older adults, gaming for non-traditional populations, and general game design, including the new area of "serious" game design [18]

4.2 Usability Testing

Due to limited budget and timeline a case study was conducted where a recent stroke survivor volunteered to evaluate the system. The stroke survivor had persistent hemiparesis that lead to impaired upper extremity function but had no severe weakness or sensory impairment of the upper extremity. The individual was able to understand and follow instructions and had a demonstrated interest in technology and games. Upon review of the gaming environment the individual had found that the use of IR motion tracking via Wii remote enabled him to successfully play the Peggle-based game. The individual confirmed that the initial chosen control regime for the rehabilitation game, tracking stroke-effected arm motion in a 2D, horizontal plane, closely approximated traditional stroke rehabilitation exercises and would therefore likely also prove beneficial. Further, the individual stated that the prototype Peggle-based game was fun and conducive to extended use, a primary goal of this research.

5 Conclusion and Future Work

This paper has described the features, design, implementation and operation of the stroke rehabilitative gaming system and preliminary findings from a case-study.

The prototype stroke rehabilitation game currently supports arm-tracking game control in 2D using only the Wii Remote's IR camera tracking ability. Future development will include also utilizing the Wii Remote's thre-axis accelerometers and the three-axis gyroscopes of the MotionPlus extension device. Combining all three sensor types, and attaching the Wii Remote to the player's forearm instead of the IR beacons, should allow full six-degrees-of-freedom (6DOF) tracking of the player's arm. Full, 6 DOF tracking of the player's arm will allow a much larger range of trackable arm motions as well as many more exercises and motions to be encouraged by stroke rehab game play.

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