Carpal Tunnel Syndrome Rehabilitation using serious games

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***Abstract*—Carpal Tunnel Syndrome (CTS) is one of the adverse effects on human physiology caused by improper computer posture and usage. It expresses a number of symptoms caused by the compression of the median nerve as it passes through the carpal tunnel of the wrist, which include pain, numbness and tingling in affected parts of the hand. CTS treatment may take the form of surgery and/or physiotherapy. This paper shows how technology-assisted physiotherapy can augment a more traditional exercise curriculum. For this purpose, a Unity3D game called Roller Ball has been developed, the scenario of which combines CTS-specific physiotherapy exercises in a naturally flowing scenario to guide a ball across a bridge. As for the game controller, we have opted for the Leap Motion sensor which has appropriate detailed wrist and hand tracking abilities.**

Keywords— Carpal Tunnel Syndrome; Physiotherapy; Leap Motion sensor; Serious Games; Unity3D game engine.

I. INTRODUCTION

Carpal tunnel syndrome (CTS) expresses a host of symptoms caused by the compression of the median nerve through the carpal tunnel of the wrist. These symptoms include pain, numbness and tingling in affected parts of the hand [1]. Many patients benefit from physiotherapy by following an exercise schedule for mobility and strength. Conservative management of CTS-related symptoms include exercises such as tendon gliding of the finger flexor tendons as well as nerve gliding of the median nerve [2], [3]. Additional exercises aim to (a) increase muscle strength in the hand, fingers and forearm and, in some cases, the trunk and postural back muscles and (b) to improve flexibility in the wrist, hand and fingers. Physical therapy helps reduce the severity of symptoms and possibly eliminate the need for surgery to help patients return to an active and functional lifestyle. Physical therapy also helps post-CTS surgery patients to restore wrist strength and to avoid bad habits that may have led to the symptoms in the first place [4].

However, it often takes weeks or months before the positive effects of physical therapy are felt. During that period, patients perform time consuming, repetitive and, as a result, boring exercises. It is fairly common for patients to start with a number of intensive physiotherapy sessions and then be given an exercise schedule to follow at home on a regular basis, checking with the physiotherapist more sparingly. However, patients may get bored due to the repeatability of the exercises and begin to neglect their home-based exercise program [5]. Accordingly in this paper we begin to explore ways that goal oriented, highly interactive computer games can provide the necessary motivation to successfully carry out a home-based CTS rehabilitation program. In fact, game features such as being in control of a 3D world, achievements, high scores, rewards and positive feedback, can draw patients to lengthier game sessions and thus speed up their recovery [6].

Sensor technology has already been integrated in game solutions. Ubiquitous motion tracking sensors such as Nintendo's Wii, Microsoft's Kinect and the Leap Motion sensor are based on different game philosophies and follow different approaches to bring motion capture to their host game platforms. Nintendo's Wii, released in 2006, was the first game console to use motion-capturing technology [7]. The Wii remote controller connects to Wii using Bluetooth with an approximate range of 9 meters and encompasses a built-in accelerometer which combines with an infrared camera to sense the remote's position in 3D space. Popular Wii-compatible controllers include the Nunchuck (which features an accelerometer and a traditional analog stick with trigger buttons) and the Balance Board which contains several sensors that calculate the mass of the player standing on it and his/her center of gravity. There have been attempts to combine the benefits of Nintendo's Wii with other projects to produce new integrated rehabilitation systems [8].

Microsoft's Kinect sensor bar was initially built as an alternative remote control to the Xbox 360 game console and was later also released for Windows PCs. Kinect contains an RGB camera and a depth sensor and employs a Natural User Interface (NUI) to enable user interaction with the game environment through gestures or voice commands. The accompanying software enables recognition of up to six players and can provide continuous skeletal tracking for two of those players [9]. The Kinect sensor tracks reasonably accurately large "macroscopic" movements of body parts, but may underestimate arm movements and overestimate leg movements by up to 30% [10].

At present, the most promising sensor for technology-based CTS-oriented rehabilitation seems to be the Leap Motion controller, a small USB peripheral device commonly placed on a table facing upward. The device uses two monochromatic IR cameras and three infrared LEDs to detect motion within a roughly hemispherical area centered on the sensor and with a radius of approximately one meter. The IR LEDs generate pattern-less IR light that can be reflected by an object (i.e. hand / fingers) over the sensor and the cameras capture that reflected light at a rate of close to 300 fps. This data stream is fed to the host computer via a USB interface, where Leap Motion's supporting software takes over to combine pairs of 2D frames generated concurrently by the two IR cameras into an accurate synthetic 3D data set for the hand.

II. The Roller Ball Serious Game for CTS Treatment

In this work we present a CTS-oriented 3D serious game called Roller Ball, a relevant screen-shot of which appears in Fig. 1. The user is called to perform extensions / flexions and radial / ulnar deviations of the wrist (shown in Fig. 2) to guide a ball across a continuously reconfigurable bridge without dropping it in the void below. The bridge is made of planks, some of which periodically move to form gaps, discontinuities or create obstacles. Naturally, the patient is expected to exercise a single hand (left or right) in a given game session.

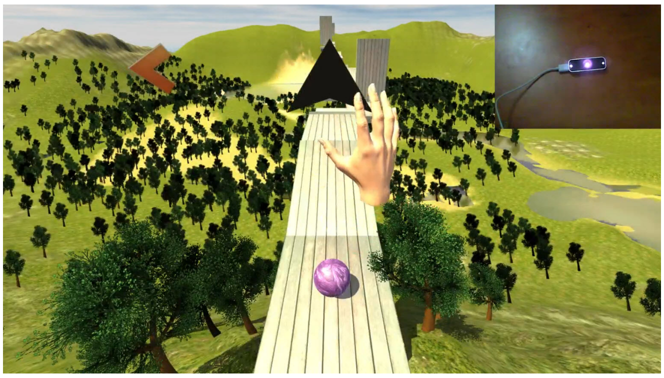

Fig. 1: A screen-shot from the beginning of the Roller Ball (the Leap Motion sensor appears in the insert in the top right). The patient uses CTS-specific exercises to successfully guide a ball across a continuously reconfigurable bridge, while avoiding a number of moving obstacles.

Even for a healthy hand and wrist, the angular extent for radial deviations is more limited than that for an ulnar deviations (in the sense that is communicated by Fig. 2). This fact alters the range of parameter values dictating successful gesture detection for each case. Further customization is possible on a per-patient basis depending on the severity of the symptoms to permit exercising to the fullest range of motion possible to a given patient.

The game scene supports the repetitive exercises that are required in CTS physiotherapy. For example, Fig. 3 relates two sample game scenes: Fig. 3 (a) requires an ulnar deviation of the left hand or via a radial deviation of the right hand to guide the ball to the left, whereas in Fig. 3 (b) the patient must perform a radial deviation of the left hand or an ulnar deviation of the right hand to guide the ball to the right. Furthermore, extension of the wrist decelerates a forward movement of the ball, while flexion moves the ball forward. These latter gestures are used in game contexts such as those displayed in Fig. 4.

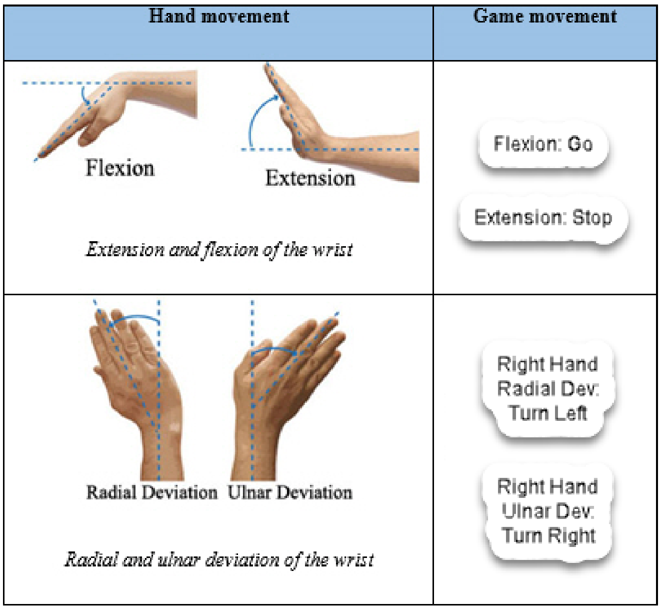

Fig. 2: Four wrist physiotherapy exercises commonly used to treat Carpal Tunnel Syndrome (left column). Each exercise is detected in the game as a gesture and is mapped onto an action on the ball as shown in the right column.

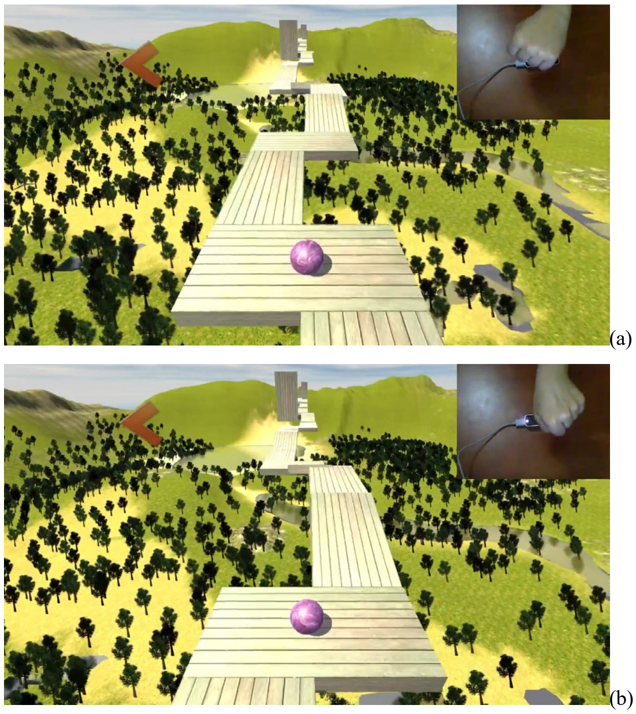

Fig. 3: The game scene in the top figure (a) requires turning the ball to the left either by radial deviation of the right hand or an ulnar deviation of the left hand, depending on which hand is being exercised. Similarly, to turn the ball to the right as is required in the game context shown in the bottom figure (b), the player must employ either an ulnar deviation of the right hand or a radial deviation of the left hand.

Obstacles situated in the game scene add to a more interesting and at the same time challenging game environment. These can be avoided and challenges can be surpassed by carefully timing and maintaining wrist-hand postures such as wrist flexions / extensions and / or radial / ulnar deviations. At the same time, these obstacles urge patients to use flexions and extensions of the wrist. For example, Fig. 4(a) shows a board further down the bridge that continuously swings between left and right so that the patient must time the movement of the ball in a way that it passes over that swinging plank quickly while it is still connects to the previous and next planks. Another challenge appears in Fig. 4(b), where the patient must wait for the rotating plank to become horizontal before venturing to pass across. In both cases, the patient must carefully combine flexions and extensions of the wrist to guarantee a safe passage of the ball across the obstacle. Additional game scenarios may employ sloped portions of the bridge along which the ball will decelerate or pick up speed due to gravity. These are intended to encourage angular deviations to much larger extents in a natural scenario-dependent manner.

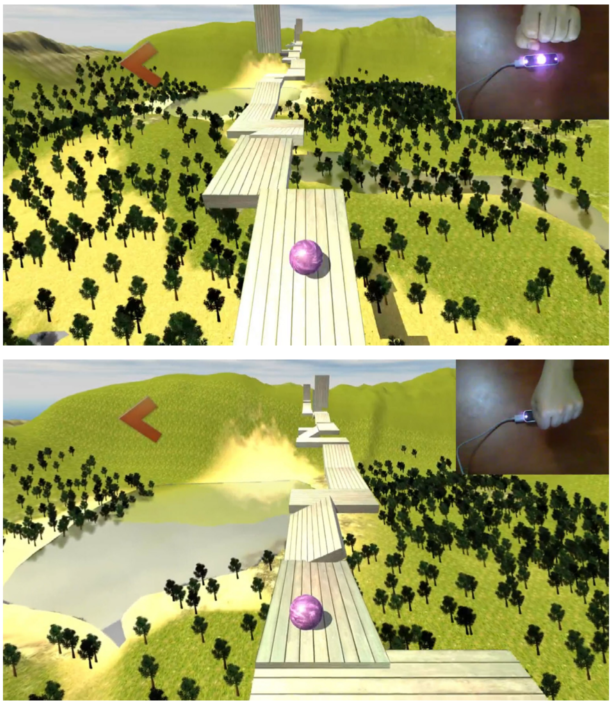

Fig. 4: Sample screen captures from the game where careful timing is required to pass the ball across the next plank to the one currently traversed. In the top figure (a) the next plank swings from right to left, whereas in the bottom figure (b) the next plank rotates about its long axis which will cause the ball to fall unless it passes while the plank is horizontal. Timing of the passage across requires a balancing act of wrist flexions and extensions.

III. Discussion and Future Work

In this work we have employed the Leap Motion sensor to create a serious game for the rehabilitation of patients suffering from Carpal Tunnel Syndrome (CTS). The Roller Ball game has been developed in Unity3D to explore the possibilities and limitations of the sensor. We conclude that the tracking accuracy of the sensor is sufficient to detect certain wrist-hand CTS-specific physiotherapy exercises as game gestures. In addition, the high sampling rate of the sensor allows for a very responsive game. Naturally, limitations in the applicability of the sensor for the intended purpose may arise in situations where the wrist-hand posture causes part of the hand (e.g., fingers) to be physically occulted by other parts. In many of these cases reorienting the sensor or attaching it on a vertical fixture easily allows an unencumbered view.

In addition, the applicability of Leap Motion sensor in physical therapy and rehabilitation is limited by the fact that it tracks only the lower arm, hand and fingers. However it does this appropriately and is responsive, so it is a good platform on which to base serious games tailored to CTS patients. In addition, the sensor can be used in conjunction with other existing platforms to be allow the calculation of additional metrics and detect and track a richer set of gestures [5]. Finally, it must be mentioned that technology-enabled rehabilitation can offer measurable results as games designed to collect performance data can enable therapists to quantitatively assess long term progress and also mitigate a valuable sense of accomplishment to the patients themselves.

Acknowledgment

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