Wiihabilitation: Rehabilitation of Wrist Flexion and Extension Using a Wiimote-Based Game System

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Abstract

In this work, the design and implementation of a "wiimote" based game system for rehabilitation applications is demonstrated. A protocol for the physical setup of the system involving a wiimote, Velcro straps, and an infrared LED circuit board stabilized by a plastic case holder has been developed. Optimal placement of reflective tape-containing straps at relevant body locations is outlined as well. The devised system involves a simple two directional (right-and-left) game that requires the flexion and extension of the wrist. A progressive in-game system has been established which provides for increasing ranges of motion as patients gradually improve their flexion and extension. The game allows for the measurement of the range of wrist motion by providing data regarding the angle formed by the forearm and the hand, using the wrist as the angle vertex. In addition, it presents a more engaging and affordable rehabilitation option for patients than what is currently available. Data concerning range of motion is very valuable to therapists in diagnostic and rehabilitative applications. This setup opens the door to future cost effective game based applications for use with other joints and motions.

Introduction

Today, stroke and wrist fractures are the most common culprits of an impaired range of motion in the wrist. Stroke, one of the leading causes of physical disability in the United States, occurs when blood supply to a certain area, or multiple areas, of the brain is severed, and control over speech, memory, and/or movement is potentially lost [1]. A fracture, or break in a bone, is an extremely common injury for which patients seek rehabilitative care. For patients under the age of 65, the most commonly fractured joint is the wrist [2].

Stroke and wrist injuries frequently result in a decrease in the range of wrist motion and require specific rehabilitative exercises that target different motions, such as flexion and extension. While wrist fractures are typically treated by use of an immobilizing cast, subsequent rehabilitation is needed in order to make the joint fully functional again.

Like most medical services, post surgical and injury rehabilitation is long, painful, expensive, and inflexible for both the patient and the therapist. Many physical therapy regimens are based on the concept of repetition, or the stimulation of muscles to achieve a range of motion or control over a specific muscle group. This eventually leads to the acquisition of "muscle memory" so that the movement becomes automatic and requires no thought. While this method has proven to be effective, the process can often last many months, and cause patients to lose motivation during his or her therapy sessions, become frustrated with technology or slow progress and reject much needed rehabilitation. Negative psychological consequences may also result from such actions and make future rehabilitation efforts almost impossible.
Coupled with high costs and inflexibility, rehabilitation has become a hassle. For example, a 15-minute therapeutic activity session in the physical therapy department of Akron General Hospital, in Akron, OH, costs approximately $69 [3]. A complete rehabilitation regiment can easily cost the patient thousands of dollars. In addition, the rehabilitation process involves multiple trips to a hospital or clinic facility. The current American medical system is not operating efficiently.

In wrist rehabilitation, the main goal is to attain an increase in the range of motion, specifically flexion and extension. Stroke and wrist injuries usually result in a decreased range of wrist motion or a decreased fluidity of movement. Using a two directional game (right-and-left), the design aims to isolate two specific motions (flexion and extension) and build a cost-effective and portable system to provide diagnostic information to the therapist and an engaging interface for a variety of patients while helping to improve range and fluidity of wrist motion.

"Wiihabilitation"

This work seeks to develop an economical solution for the rehabilitation of the wrist for patients who have suffered from a local stroke, or a wrist fracture, and subsequently lost range of motion. Our setup involves the use of the infrared detection capabilities of a Wii videogame controller in order to track and motivate the user to play an engaging game that promotes the rehabilitation of his or her wrist. Ideally, this solution can be implemented such that rehabilitation can be done affordably from home to minimize the excessive cost of rehabilitation that plagues patients today.

Types of Wrist Movements

The types of movements that the project is looking to rehabilitate are flexion and extension of the wrist joint. Flexion is the act of decreasing the angle of the joint. In the case of the wrist, this is bringing the palm side of the hand towards the anterior side of the arm. Extension is the opposite motion of flexion, and includes increasing the angle of a joint. For the wrist, this means bringing the posterior side of the hand towards the posterior side of the forearm [4].

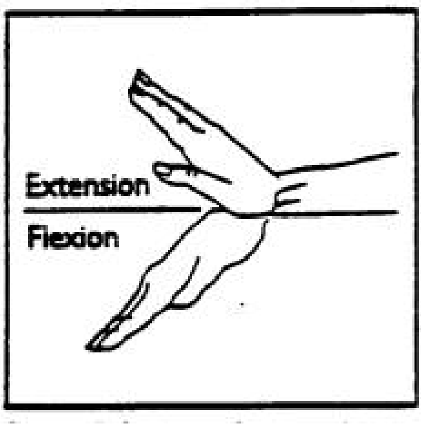


Figure 1. Diagram displaying the extension and flexion [16].

Wrist Injuries

This project is looking to help patients recover from several types of wrist injuries. These include both traumatic injuries, such as fractures, and debilitating conditions like strokes. According to eMedicine's 1998 statistics, an estimated 1,465,874 hand and forearm fractures were observed in the United States, which amounted to 1.5% of all emergency department visits for that year. Of these, 44% were radius and ulna fractures and 14% were carpal fractures. Wrist fractures tend to happen in "young, active, and energetic males" and "elderly people with osteoporosis". These types of fractures usually result from "axial loading on an outstretched palm and extended wrist" [5]. This can happen through a fall on an outstretched hand, a motor vehicle accident, or a sports accident. A stroke is a lack of blood flow to a part of the brain, which can result in death of brain cells, leading to physical impairment. In the cases of both fractures and strokes, the key to rehabilitation is repetitive movements. Repetitive motions can help improve muscle memory, in which neuron pathways are strengthened, allowing for quicker communication to muscles and finer motion control.

Wiimotes

The wiimote was released in 2006 by Nintendo as the hand held game controller for its sixth game console named the Wii. Intended for use as an accessible way to engage a wide variety of people of all ages, the wiimote is held in the hand like a remote control and tracks motion and hand movement by an infrared (IR) camera. The camera has a resolution of 1,024 x 768 pixels, four bits of dot light intensity, 100 Hz refresh rate, and 45 degree horizontal view. Manufactured by PixArt Imaging, it features an integrated multi-object tracking (MOT) engine. The MOT engine provides high resolution and high speed tracking for a maximum of four simultaneous points. Using this technology, the Wii "sees" or tracks two groups of LED infrared lights in the sensor bar provided by Nintendo with the Wii console. The software then uses a Bluetooth connection to send the x,y coordinate data using the console. An ADXL330 accelerometer provides three dimensions of acceleration data which can be used to obtain data regarding movement velocity [6]. The Bluetooth capability however can also be used to connect the wiimote to other Bluetooth enabled devices such as computers. This very technology has attracted a wide audience to search for other uses for the wiimote, from composing music in the Kyma X environment to rehabilitation. The wiimote is sold at retail price for approximately $40 USD, making it an economical and powerful solution to expensive inpatient rehabilitation in medical facilities [6].

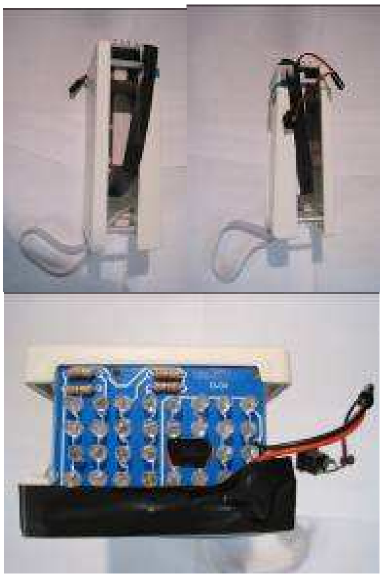
C#

The program for the game that the user plays is written in the programming language of C#, which is a part of the .NET Framework. The reason that the program was written in C# was that the wiimote library that the project references was written in C#.

Methods

The “wiihabilitation” setup that has been developed consists of an off-the-shelf Wii remote, three simple Velcro straps with appropriately placed reflective tape, and a basic infrared LED array. All components of this setup are relatively inexpensive in comparison to existing rehabilitation equipment, and can be realistically assembled by a patient in his or her own home.

For the purposes of this rehabilitation-oriented game, the user is seated with his or her arm resting on an elevated surface (a chair in this study) while the wiimote rests below. The wiimote is spatially oriented such that the directional arrow keys (front) are facing the user. Infrared sensors housed within the wiimote are pointed up towards the user’s arm so that wrist motion can be captured and an LED array with a hole cut in the middle is then placed above the wiimote so that the IR cameras in the device have a line of sight through the hole. To ensure that the wiimote and IR array remain in the correct orientation, a plastic casing has been modified to fit the devices thereby adding structural stability to the setup. The increased steadiness of the casing allows infrared light emitted from the LEDs to be mirrored off of reflective tape secured to the user’s arm in a relatively straight line so that data collection and game-play can be facilitated.



Right, Left and Top Views

Figure 2. The setup of the wiimote, showing the plastic case holder housing the wiimote and the infrared LED array.

Three Velcro straps are placed around the wrist, the forearm approximately 7 centimeters below the wrist, and the palm, just behind the user’s pinky finger joint. Pieces of reflective tape attached to the Velcro straps measuring approximately one centimeter in width and five centimeters in length face down towards the IR cameras in the wiimote. Movement by the user is then tracked by analyzing changes in the angle of the wrist.

Figure 3. The placement of the reflective tape on the user’s arm.

In order to begin game-play, the wiimote has to be put into “discovery mode” which allows a Bluetooth-enabled computer to detect it. Once located, the wiimote can be added to the computer’s list of Bluetooth devices so that interface between the wiimote and computer can be accessed. The user then opens the game enabling them to the Pong-like game using his or her wrist motion.

The main game is an easily modifiable program, greatly reminiscent of Pong, in which the user controls one of the paddles through the degree of flexion and extension of his or her wrist. In this game, the user must move a paddle along a horizontal axis in order to keep a ball bouncing in the game screen.

Figure 4. The orientation of the wiimote and the user’s arm when in a sitting position.

A calibration mode has been developed in order to tailor the game to the specific rehabilitative needs of an individual user. The calibration mode requires the user to extend his or her wrist to his or her full range of flexion and extension by asking them to reach for two objects on opposite ends of the screen. The target points however, are artificial points that serve purely as a motivation tool for the user; the calibration itself is based on the free motion that is detected. As time passes, a scaling factor is gradually decreased, thus increasing the range of motion required to move the paddle. The starting level for the actual game has an initial scaling factor that is based on the user's maximum range according to the calibration. Calibration takes twenty seconds provided the subject does not move excessively during the process.

Figure 5. The calibration screen for the wiimote game.

As the user continues playing the game, adjustments to the scaling factor are made that reflect improvements in his or her range of motion. These changes are seamlessly integrated so that the user does not notice the difference and therefore they are kept involved in the game-play. Over time, the scaling factor is decreased to such a degree that the user is moving with a healthy range of motion (approximately 189 degrees) [7].

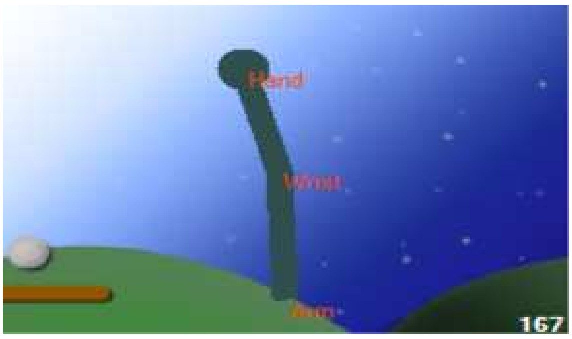


Figure 6. Game display that shows the angle of wrist flexion/extension (bottom right) and spatial position of the user's arm (center).

In order to detect, isolate, and smooth the motion of a user's wrist, a computer algorithm is employed. The infrared sensors of the device divide the range of detection into sets of 4 pixels which are registered as one area. Hits in these areas are then tracked at a rate of 100 frames per second (100 Hz) [6]. A greater number of hits in one area corresponds to a more reliable point and thus an area that probably contains a piece of reflective tape. Subsequently, circles are constructed around the points and any weaker points that fall within the radii of stronger ones are "ignored". This results in more reliable points taking precedence over less reliable ones in terms of determining the approximate locations of the pieces of reflective tape on the user's body. The three strongest points are chosen and established as the relative locations of the user's wrist, forearm, and palm.

A triangle is constructed from the three strongest points and using the Law of Cosines the angle of the wrist is determined. Since the distances between the reflective points is essentially constant, the furthest distance between two points must have corresponded to the points on the user's palm and forearm due to the anatomical constraints of the average human body. Geometrically, this imaginary line between the two points is the hypotenuse of the triangle and the angle opposite to this is the desired measurement for our study. So using the Law of Cosines the value of the angle is determined. Due to the lack of mathematical differentiation between two angles (such as 210 and 150 degrees) in such a triangle, directional vectors of the user's motion are taken into account to aid in selection of the correct angle measure. Directional vectors perpendicular to the line along the arm and hand essentially "point" to the actual angle of the wrist. A positive sign corresponds to the extension angle of the wrist while a negative sign indicates the flexion angle.

Over the course of a few game-based rehabilitation sessions the user's progress is tracked by analyzing the change in his or her range of motion. Data regarding the user's average and maximum ranges of motion reported by this system is kept for the physical therapist's records as well as for in-game adaptation to each user's specific needs. In this way, both the rehabilitative and data-collecting benefits may be maintained while the user remains engaged in his or her therapy session.

Before the game begins, physical therapists are given the option of altering the movement of the ball. By selecting the frequency (expressed in percentage) with which the ball moves towards one side of the screen or the other, physical therapists are able to stress either the flexion or the extension motion. So if a user has a problem with the extension of his or her wrist, then his or her physical therapist could choose to send a greater percentage of the balls towards the extension side of the screen thereby isolating the problematic motion. In this way, the session provides a greater rehabilitative effect and, in the long run, shortens the rehabilitation time.

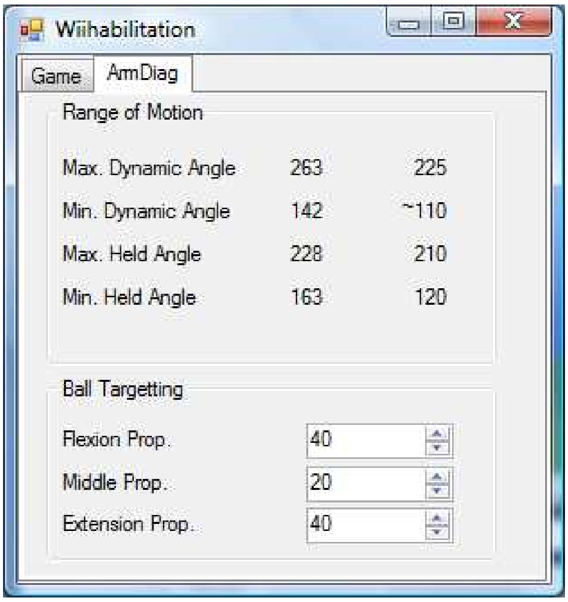


Figure 7. Information screen that displays user's movement data. Physical therapists may also input percentages focusing on different degrees of flexion and extension.

Results and Discussion

Though the use of a wiimote and other simple pieces of hardware, it has been demonstrated that an at home rehabilitation system can be created. A simple Pong game played by controlling the paddle through angular motion of the user's wrist and an efficient algorithm have been successfully developed for the detection and isolation of the three strongest reflective points. These reflective markers represent the three points that form the wrist angle and allow the user to move the paddle across the screen. Calibration readings taken at the beginning of the game determine the user's baseline range of motion and are used to create the scaling factor for the first stage of the game. This factor is then altered as the user's range of motion improves and is eventually restored.

After meeting with two medical professionals, Carey Glass, CPO, FAAOP, a prosthetist-orthotist, and Dr. Steven Escaldi, D.O., a physitrist from JFK Institute for rehabilitation, it was independently confirmed that such a game would provide rehabilitative effects. For stroke survivors it was said to be particularly important to engage in repetitive motions. Using the system, it would be very easy to have a user carry out the same motion repeatedly and thus help him or her strengthen neural connections in the motor cortex. Moreover, both physical therapists agreed that it would greatly facilitate the rehabilitation process for users if they actually enjoyed the exercises. By utilizing an entertaining game-like setup, we can encourage patients to continue his or her sessions and possibly improve his or her overall morale [8].

The benefits of this system are also not limited to modern areas of the world. Based upon the level of technology we used both in implementing the software as well as constructing the hardware for our system, it is well within the realm of possibility to export the "wiihabilitation" system to other countries. In order to operate this system, the user would simply need access to a flat surface, computer, wiimote, and LED array, all of which could be distributed through the mail. This would allow a considerable portion of the world's population to gain access to the system. The relatively low cost of the system, about $450 USD, compared to other rehabilitation methods also serves to greatly augment the number of people who have access to "Wii-habilitation". Even if individuals themselves did not own all of the discrete components, they could acquire them on a borrow-basis from local physical therapists and/or doctors.

Related Works

Motion Tracking Using Multiple Wiimotes. In recent years, wiimotes have been commonly used as cost-effective alternatives to expensive, finely tuned motion tracking cameras in motion analysis [9]. Applications of such studies have ranged from rehabilitation to musical education [10,11]. Some studies call for the use of two wiimotes and other technology (i.e.: force grip) to provide raw data from a remote location to the therapist via secure communication [10]. Though it is important to note that previous studies have focused on grip rather than joint rehabilitation, this design presents a new idea that incorporates the spirit of the mentioned study. However, by eliminating the cost of one wiimote and the need to calibrate hardware, this project provides a more cost effective and less cumbersome alternative to rehabilitation and therefore the system becomes more portable and may be more accepted by the targeted audience.

Virtual Reality Rehabilitation. As mentioned before, rehabilitation is based on the principle of repetition, making treatment boring and unattractive to patients. As the internet and virtual reality technology becomes proliferate and accessible, many researchers have begun to look into virtual reality alternatives on the computer and other mainstream gaming consoles (Xbox 360, Wii, PlayStation) to provide accessibility and interest [8,12,13,14,15]. However, most Wii related games used the wiimote accelerometer as its primary source of data, requiring the patient to hold the wiimote and limiting its audience to patients who can grasp objects with their hands [8,14,15]. This design does not use such an assumption and provides an arrangement to accommodate patients who can and cannot grasp hand held items in a comfortable, natural position to rehabilitate the wrist.

From another perspective, games always involve a certain level of cognitive ability. According to gaming studies, certain games appeal to certain age groups: Generally, games that are particularly "hard" or rely on strong cognitive abilities are more appealing to younger audiences, while simple games appeal to older audiences. Some rehabilitative games for the wrist have involved memory and did not have different levels of difficulty. Recognizing possible frustration with the game from boredom or static difficulty, this project presents different game play that is easy but increases complexity in accordance with the patient's performance.

These interactive rehabilitation methods greatly differ in programming languages, calling for the user to participate in a particular role-playing world or using a particular game system: One study called for the user to rehabilitate in the "Second Life" world, an online RPG gaming environment [14]. . This idea can be expanded to control the mouse cursor, allowing for the user to play any two-directional game available on the Internet. Though this particular project was programmed in C# due to the availability of the wiimote library, future applications can be programmed in any language to suit the needs of the user.

Conclusion

From this work, it was concluded that range of motion rehabilitation through the use of a wiimote technology based system is very much a feasible, effective, and inexpensive option. It offers patients a more engaging alternative to the current system of rehabilitation. Furthermore, it widens the availability of physical therapy and makes this type of care possible for many people in the developing world. In this work, the range of motion of the wrist joint was picked as an ideal candidate for this rehabilitation system. The successful development of a wrist motion based game opens the door for a variety of motion based rehabilitation games for other body joints such as the elbows, shoulders, and/or the knees. Implementation of this system will begin at rehabilitation departments in medical centers and gradually expand outwards to private physical therapists and eventually to individual homes.

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