Wiimote-iPhone Interface Applications for Neuromuscular Rehabilitation

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1 Abstract

The goal of our design project was to create a reasonably priced, portable, and effective neuromuscular rehabilitation device. The most integral part of this design was Bluetooth communication between a motion-capture instrument with an accelerometer and a processor that would display a responsive user interface in the form of a game. We implemented this by interfacing two iOS devices (iPhone / iPod Touch), one of which acted as a server for a rehabilitation application while the other was used to quantify acceleration.

We isolated and measured pronation and supination of the upper limb by requiring the disabled user to hold the motion-sensing iPod as they rotated their forearm within a certain angular range. This range was determined by measuring the user’s maximum range of motion. As the user carried out this motion, he or she received feedback in the form of a point system for a simple game. More points were awarded if the forearm was rotated at a constant velocity or if the patient had increased control over the rotational velocity of the forearm. Data was collected in the form of angular position of the iPod at a set of given times. Our application also prompted users to email this data to their attending physician, who could then interpret the data and use it to track improvement in range of motion after rehabilitation.

2 Introduction

Stroke and joint damage are the two most frequent causes of disability in the US. [1] Over two-thirds of stroke survivors require rehabilitation therapy and less than 10% regain full functional usability of their upper and lower extremities. [2] A stroke is caused by blockage of blood to the brain and subsequent oxygen deprivation of the nerve cells. Cell death then impedes the brain’s ability to communicate with muscles and thus hinders motion. [3] Joint damage is a term that encompasses a large number of injuries for which patients seek rehabilitative care. These injuries are a result of trauma to a joint or its surrounding muscles, tendons, and ligaments. Stroke and joint damage both limit a patient’s range and fluidity of motion. In order for patients to regain full function of their limbs, they need to undergo neuromuscular rehabilitation. [4]

The fundamental goal of any patient undergoing rehabilitation is to learn how to execute a range of motions integral to daily life. Typical rehabilitation regimens are focused on the repetition of isolated movements. [5] By constantly stimulating certain muscle groups, patients eventually acquire the muscle memory needed to incorporate these movements into everyday tasks such as opening doors and handling utensils.

However crucial physical rehabilitation may be to the recovery process, cost and inflexibility are major concerns that limit the number of patients with access to rehabilitation devices and programs. For the average clinic, the initial capital needed to purchase commercial devices may well exceed $50,000, not including the money needed to train staff members. Thus the average cost of rehabilitation for an individual is over $10,000. [6] Rehabilitation also places a burden on the patient’s family because of the perpetual need for transportation to and from the medical facility.

Because rehabilitation is a long and tedious process, it requires active patient participation and a constant source of motivation, but often patients become discouraged by the high costs and time-consuming therapy sessions as well as the slow rate of progress. [5] Because this loss of enthusiasm seriously hinders improvement, there is clearly a need for a low-cost, portable, and engaging rehabilitation system.
By interfacing two iPod Touches, we decided to build an effective and comparatively inexpensive rehabilitation system. Note that this rehabilitation system can also be utilized with two iPhones or a combination of an iPod touch and an iPhone. Using a simple game that records and responds to rotational motion, the design isolates the movements of supination and pronation for rehabilitation. The system is able to provide visual feedback to the patient and diagnostic information to the therapist. Our application brings a new universality and ease to rehabilitation for users—especially those post-stroke patients who may not be able to travel to a clinic because of their disabilities. In essence, those who own two of the aforementioned Apple devices will be able to download a free, at-home rehabilitation system, saving a tremendous amount of money and hassle.

3 Background

3.1 Neuromuscular Rehabilitation

Neuromuscular rehabilitation is a critical aspect of recovery following neurological injury as well as direct injury to the limb. Often, patients recovering from serious neurological damage, especially following a stroke, must relearn the most fundamental motor skills through constant repetition of the impaired motion. Rehabilitation through recurrent and measured motion is called explicit learning, and is often discouraging and tedious. [7]

To motivate patients and counteract the monotony of these routines, physical therapists often use an implicit learning approach, the acquisition of skills through indirect means. Specifically, physical therapists implement games that involve movements similar or identical to those needed to induce neuromuscular rehabilitation. Often the patient is unaware of what is being learned, or even that learning is taking place. For example, certain clinics use games with joystick steering to train wrist movement. Studies have shown that patients who learn movements through implicit learning in a virtual environment are more likely to use those movements successfully in real-life situations than those who learned through explicit learning. [5] The game designed in this project is an example of the implicit learning model.

The movement we are targeting for rehabilitation is pronation and supination of the forearm, a twisting rotational motion from a palm-down to a palm-up position. This ability is often lost in post-stroke patients or those suffering from other upper-limb disabilities. Often rehabilitation routines are designed for either kinematic or dynamic improvement—a kinematic routine aims to increase motion speed and control, while a dynamic one enhances muscle strength itself. Since most everyday tasks that involve pronation and supination, such as turning a doorknob or a screwdriver, require more finesse than force, our rehabilitation application is kinematic rather than dynamic.

Figure 1: Pronation and supination of the forearm.

Currently, “Motion Capture” is being applied to medical rehabilitation in order to accurately quantify and model bodily movement. Motion capture is the creation of a 2D or 3D representation of a live action. A motion capture device records, then processes or transmits information about the user’s position, velocity, or acceleration so it can be displayed on a user interface. This application utilizes motion capture in the form of data collection by one iPhone, dual-device communication, and a responsive display on the other iPhone’s user interface.

3.2 Game Kit and the iPod Touch

The two devices used in this project were both iPod Touches—multipurpose media players capable of Wifi and Bluetooth connections. Both devices ran on iOS 4.0, an operating system capable of sending emails and multitasking. Both implemented Apple’s Game Kit interfacing framework, code that enables peer-to-peer connectivity. This connectivity is achieved through creation of a Bluetooth network.

3.3 The iPod Touch and the iPhone

The iPod Touch is a multimedia player with Wifi and Bluetooth connectivity. The typical iPod Touch user enhances the device’s functionality by purchasing a variety of applications from the Apple App Store. These apps may be anything from games to GPS-based location finders, and
## Cyberglove vs. Wiimote-iPhone System

<table>
<thead>
<tr>
<th></th>
<th>Cyberglove</th>
<th>Our System</th>
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<td><strong>Cost</strong></td>
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<tr>
<td><strong>Bluetooth Interface</strong></td>
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Figure 2: This table compares the attributes of a common upper-limb rehabilitation device with the application described in this paper.

Apple Developer’s License.

The iPod Touch has three generations, or different hardware configurations, but the development devices used for this project were two second-generation iPod Touches with 8G of flash memory and 128 MB of RAM, running on the iOS 4.0 operating system. These characteristics are technicalities; our application is functional if implemented with devices running any version of iOS, excepting the first generation iPod Touch or iPhone, which do not support Bluetooth. Although each iPod Touch has an internal accelerometer, this project uses only one for its motion-sensing capabilities and the other for its 3.5 inch screen and the internal processor needed to receive and display data.

The iPhone is a smartphone capable of connecting to the Internet and third-party Bluetooth-enabled devices as well as placing calls. Because it can communicate through Bluetooth, the iPhone can also be used as one or both of the devices in this dual-device application.

### 3.4 Bluetooth and the Wiimote

The dual-iPod Touch application described in this paper functions as a proof of concept for a future Wiimote-iPhone system. The Wiimote, like the iPod Touch or iPhone, is Bluetooth-enabled and contains an accelerometer that provides data readings in three axes. Because the Wiimote also connects to Apple devices through Bluetooth, our preliminary design shows that it is possible to use Bluetooth to implement motion capture with two wireless devices. It is also possible to remove the code that controls dual-device data transmission and replace it with new code for signal transmission between the iPhone and Wiimote.

### 3.5 X-Code and Objective C

All iPod touch or iPhone applications are tested and debugged in Apple’s XCode development environment, although they can be written in several programming languages (C, Objective C, or C#). This application was mainly written in Objective C, an object-oriented language strongly influenced by the procedural language C. Cocoa Touch, an addition layer on top of Objective C with high level APIs, is the framework that assists in the creation of the user interface. Interface Builder, a separate but equally important application, was also used for the development of the graphical user interface.

### 4 Designing a Dual-iPod Touch Rehabilitation Application

#### 4.1 Dual iPod Touch Interface

We built a low-cost rehabilitation system consisting of two iPod Touches, both operating on iOS 4.0. We used one of these iPod Touches as a motion capture device which transmitted its accelerometer data across a Bluetooth connection at a rate of 20 data sets per second. Each data set consisted of three variables—the acceleration along the x, y, and z-axes, measured in gravitational constants, Gs. In our proof of concept application, this iPod Touch exemplified the feasibility of using any other Bluetooth-enabled device which contains an internal accelerometer.

While the first iPod Touch was used for its motion-sensing properties, the second provided our application with a processor and displayed a user interface. This was the device that received the aforementioned data sets over a Bluetooth link, isolated acceleration values along a single axis, and integrated these values into a responsive user interface which it then displayed. While the motion-sensing iPod Touch was identified as a client, this iPod Touch acted as a server on which we ran our application.

In order to implement gameplay, we established a Bluetooth communication between the two iPod Touches using an interface which had previously been set up and distributed by Apple. Thus this project made use of preexisting open-source code available in the Apple Developer’s API under the name “Game Kit”. This Game...
Kit framework and sample code were originally intended to implement peer-to-peer connectivity for multiplayer games.

4.2 Original Gripper-iPhone Interface

The other auxiliary device that we considered for this project was a grip-force dynamometer (GFD) which would have been connected to the iPhone through the audio port. The GFD, which has previously been integrated with specialized hardware in alternate rehabilitation setups, measures cylindrical grip force and outputs data in the form of a changing DC voltage depending on the amount of force being applied.

We eventually chose not to implement this particular design because it would have required modification of the iPhone’s internal hardware, which contains a high-frequency filter designed to remove all DC signals. Although there were alternate ways to create a successful interface, such as attaching a voltage-controlled oscillator to the gripper to convert its current from DC to AC form, we felt that a motion-capture application would have been more versatile and effective for rehabilitation purposes.

4.3 Calibration

The accelerometer readings varied by approximately 0.02G when they were taken in rapid succession. We accounted for the intrinsic variation in accelerometer data by asking a first-time user to calibrate the device. To calibrate the device, the user is asked to place the iPod Touch first screen-down for two seconds, then screen-up for two seconds. During these periods of time, the application takes six z-axis accelerometer readings—3 while in the screen-down position and 3 while screen-up. Both sets of three readings are then averaged to arrive at two numbers: the acceleration along the z-axis when the iPod Touch is screen-down, and the acceleration when it is screen up. All other accelerometer readings are then compared to these numbers to find the angle of the iPod touch relative to the flat surface upon which it was placed during calibration.

4.4 Range of Motion Test

Like in any traditional rehabilitation program, an initial measurement of the patient’s capabilities is a must. Patients are “baselined” in order to determine their initial range and fluidity of motion. Our application requires the patient to rotate his or her arm to the greatest degree possible. The two most extreme positions are then recorded based on the most extreme values of acceleration along the z-axis. The application takes this measurement before each run session.

After the range of motion test is taken, the angle between the two most extreme positions is determined to be the patient’s range of motion at that time. The application then scales its dial so the patient will only be required to rotate their forearm within this angle. This prevents the patient from overexerting him or herself and
worsening their injury. Ideally, the range of motion will increase slightly throughout the course of several sessions as the patient becomes accustomed to repetitive rotation within a set angle.

4.5 Gameplay

Following calibration, the main body of the application is a simple game designed to minimize distraction while still providing real-time feedback on the user’s progress. At the start of the exercise, the iPhone displays a white semicircle with a black line at 90° (in the center of the semicircle). The game begins three seconds after the user presses the begin button. At this time, a blue sector appears which has both of its radii located at 90°, and the black line starts rotating with a constant angular velocity. The user must turn the Wiimote while transferring from a pronated to supinated position and back. This motion causes the sector to widen as one radius rotates in the same direction as the forearm is rotating. The object of the game is to follow the moving black line with the moving edge of the sector as closely as possible. The user gains ten points if the edge of the sector is within 20° of the black line during any given iteration. The sampling rate is 20 iterations per second and the black line moves approximately 2° per iteration. The point counter is shown on the screen throughout the duration of the game, providing a constant source of motivation and visual feedback for the user.

4.6 Data Capture and Interpretation

At the end of each session of gameplay, the user is prompted by the below screen to send their data via email to their attending physician or physical therapist.

The data is sent in the form of angles, measured in degrees, of the motion capture device at every $\frac{1}{20}$ interval of time, measured in seconds. This requires the application to convert the acceleration values along the z-axis into angular values—this is calculated using the below equation.

$$\theta = \arccos a_z$$

The total game consists of 457 iterations, spanning 900 degrees of motion. The data can easily be plotted and interpreted to provide valuable information about the patients status and progress. The graph of Angle vs. Time easily allows the therapist to see the maximum range of motion of the patient. The 1st derivative of angle, velocity, versus time can be used to identify the intervals in rotation where the patient is struggling most. The 3rd derivative, jerk, can be measured and used to measure how jerky the rotation is.
5 Results and Discussion

![Figure 7: Angle vs. Time Graph](image)

Our application was effective in processing the angular change characteristic of normal motion. This graph above portrays the angle vs. time curve of the motion of an unimpaired user. Note the approximately smooth, sinusoidal quality of the curve. The graph of angle vs. time for a disabled user would hypothetically then show some deviation from this curve.

6 Conclusion

6.1 A Convenient and Effective Rehabilitation System

We found the range of motion rehabilitation therapy provided through the iPhone-Wiimote interface to be an effective alternative to conventional rehabilitation therapy. With the comparatively low cost of materials, it broadens the audience of rehabilitation therapy, making it accessible to those in difficult financial situations around the world. In our work, we picked supination and pronation as an ideal candidate for proof of concept. By interfacing two Bluetooth enabled devices, the iPhone and an iPod Touch (simulating a Bluetooth enabled Wiimote), we successfully developed a game based upon the rotational motion of the wrist. The immediate visual and diagnostic feedback, supplemented by the engaging game interface, motivates the patients to improve. At the end of every session, diagnostic information may be sent to the therapist, making our rehabilitation game a useful adjunctive tool. It permits for extended in-home therapy sessions, allowing quicker recovery of patients. Implementation of this system may create a gradual shift of rehabilitation away from the clinic into the home.

6.2 Future Work

The successful implementation of our proof of concept design demonstrates the feasibility of interfacing an iPhone with any Bluetooth-enabled device which contains an internal accelerometer. The next logical step of our project will be to directly interface the iPhone and Wiimote rather than programming for a two-iPhone interface. Because many people already own an iPhone and Wiimote, the iPhone-Wiimote setup will be even less costly and more universal.

The Wiimote also has an adjunct known as the WiiMotionPlus, which uses a gyroscope to measure velocity. By reading data from the WiiMotionPlus rather than just the Wiimote accelerometer, we will be able to more accurately describe the patient’s kinematic motion.

![Figure 8: Wiimote With and Without WiiMotion Plus Adjunct](image)

The development of a program that facilitates forearm rotation implies that applications which rehabilitate other movements can also be created. It is entirely possible to isolate acceleration along alternate axes in order to measure knee flexion and extension or shoulder rotation.

Finally, the idea of interfacing the iPhone with an auxiliary rehabilitation device is a versatile one which can be implemented using forms of communication other than Bluetooth. We hope to explore the alternative use of a gripping device which connects through the audio jack. Furthermore, a variety of other adjuncts can be interfaced through the audio jack—for example, devices that measure

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