Java Therapy:
Web-Based Robotic Rehabilitation

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Abstract. Brain injury as a result of stroke and trauma is a leading cause of disability in the U.S. Unfortunately, little technology is currently available for individuals with brain injury to practice and monitor therapy on their own at home. This paper describes an inexpensive robotic telerehabilitation system for arm and hand therapy following brain injury. "Java Therapy" is a Web site with a library of evaluation and therapy activities. The activities can be performed with a commercial force feedback joystick, and the joystick can physically assist or resist in movement as the user performs therapy. The system also provides quantitative feedback of movement performance, allowing users and their caregivers to assess rehabilitation progress via the Web.

1. Introduction

In the U.S. each year, over 600,000 people suffer a stroke, and approximately 80% of the survivors lose arm and hand movement skills [1]. Physical and occupational therapy are essential to recovery, and typically include hands-on manipulations, such as passive range of motion exercise and active assistance of desired arm movements. These manipulations are designed to reduce contracture and spasticity, to enhance sensory input, and to demonstrate desired movement patterns. Movement skills improve with increasing levels of therapy, and with increased use of the affected extremity [2-4].

Unfortunately, economic pressures on the U.S. health care system are causing individuals with a brain injury to go home sooner and receive less therapy. Compounding the problem, there is currently a lack of technology available for practicing self-initiated therapy at home. To address these needs, several research groups including our own are developing robotic devices, termed "rehabilitators", that physically interact with people to stimulate the senses of touch and movement, and retrain coordinated movement [5]. Encouragingly, initial clinical trials with the MIT-MANUS [6], MIME [7], and ARM Guide [8] rehabilitators indicate that these devices can significantly improve arm movement ability in both acute and chronic stroke subjects.

Despite their promise, current rehabilitators are limited by their cost and size. The "ARM Guide" is relatively simple in its design, using only one motor while allowing 3-space motion, but would still require several thousand dollars to manufacture. Production cost estimates for MIT-MANUS and the MIME device are considerably higher. These rehabilitator designs are also heavy and require substantial operating space. While acceptable

Figure 1: *Prototype web-based, force feedback telerehabilitator ("Java Therapy")*

for well-equipped exercise gymnasiums in large rehabilitation centers, the high cost and large size of current rehabilitators limits the devices' accessibility to smaller rehabilitation clinics, and precludes their home use.

The advent of dynamic force feedback technology for the PC, coupled with the networking power of the Internet, could solve these problems. Commercial force feedback joysticks designed primarily for gaming applications can not only sense a person's movement, but can also apply forces during movement. Like existing robotic therapy devices, such devices could be used to stimulate the sense of touch and movement, and could apply therapeutic patterns of forces to the hand and arm as the user attempts to move. Unlike larger robotic devices, however, force feedback joysticks could become truly accessible personal movement trainers because they are already in mass production and can be purchased at low cost. By networking them to rehabilitation centers through the Internet, such devices could provide a means for an individual with a brain injury to access a personalized program of therapeutic exercises, customized by a rehabilitation expert. The device's ability to measure and record motion could provide a means to quantitatively monitor rehabilitation progress, allowing users to receive detailed, motivating feedback. Also, networking could provide a means for rehabilitation providers to track the user's sensory motor performance while the user stays at home. In summary, because of the commercial advent of affordable force feedback devices and the Internet, there is an excellent opportunity to make robotic upper extremity therapy a viable aspect of home-based telerehabilitation programs that have recently been advocated [9,10].

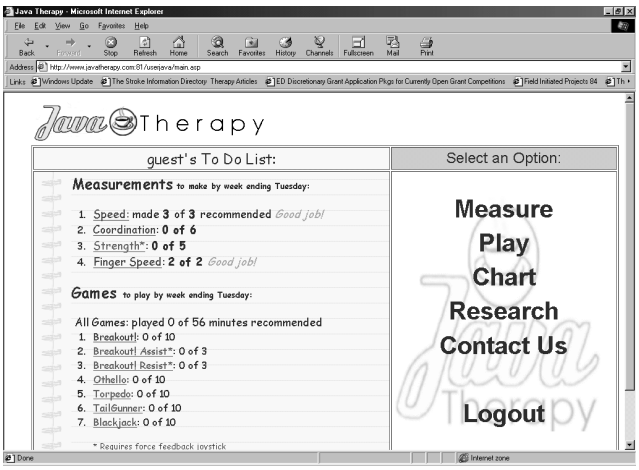

Figure 2: *Java Therapy main web page showing "To Do List" and Main Menu.*

As a first step in addressing this opportunity, we have developed a prototype system called "Java Therapy" [11] (Figure 1). The mechanical components of the system are a low-cost, force-feedback joystick, a custom clip-on splint for individuals without hand grasp, a mobile arm support, and a custom support base. These components' total cost is less than $200 and they can easily fit on a tabletop. The software consists of a Web site with a library of rehabilitation status test, therapy games, and progress reports written in the Java programming language (Figure 2, also see http://www.javatherapy.com). This paper overviews the system design and describes use of the system by a chronic stroke subject.

2. System Design

Software Design Philosophy: Two approaches to the software design were considered. The first was to develop a stand-alone program that could be installed on a PC, which would control the joystick and transfer information through a temporary network connection. The second approach was to incorporate force feedback into a Web page using a Java applet, and to use this Web page to transfer desired information. The second approach was chosen for two reasons. First, since Java applets are downloaded onto the host computer each time a Web page is accessed (Figure 3), new versions of the therapy program could in effect be automatically installed each time a user accessed the therapy web page. This was attractive not only for facilitating rapid modifications during the early development of the system, but also for providing a means for personalization of therapy plans. In effect, new Java therapy applets designed at a remote center could be downloaded "on the fly". The second

advantage was the platform independence of Java. Using any Java-enabled Web browser, users on a variety of computing platforms, with a variety of input devices, could access therapy.

In order to control the joystick through a Java applet, we used FEELtheWEB software developed by Immersion Corporation. FEELtheWEB is an ActiveX control for browsers like Internet Explorer 4.0 that can apply forces to the joystick and receive function calls through HTML.

Prototype Therapy Game and System Testing: As described in detail in [11], a prototype therapy game with force feedback was developed to test this software design concept. In the therapy game, the user was asked to move a circular cursor into a square target with a Microsoft Sidewinder Force Feedback Joystick as quickly and accurately as possible (see Figure 4). After a delay, if the user had not yet moved into the target, the motors on the joystick activated and assisted the hand in moving into the target. This continued with the target changing positions to span a 360-degree range of movement directions. Upon completion of the game, movement time for each trial was posted to a remote server computer.

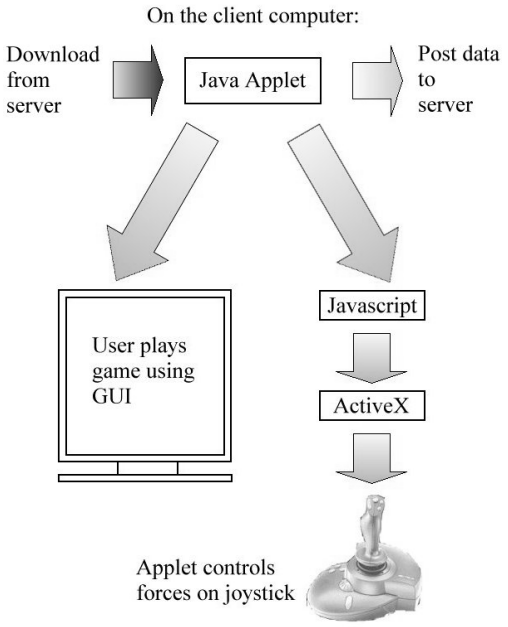

Figure 3: *Client Side Processing with Java*

Three people with hemiparesis resulting from stroke tested the joystick system at a local outpatient rehabilitation center. It was found that the forces helped the subjects move more quickly into the target, with the greatest improvement shown for the most impaired subject. These results demonstrated that the joystick system is strong and accurate enough to assist in moving stroke-impaired arms. In addition, the subjects used the system several times a week for three weeks to practice arm movement, achieving hundreds of practice movements. By analyzing data posted to our server, changes in the subjects' movement ability were tracked. These results demonstrated the feasibility of providing and monitoring therapy activity using the Java-applet/Web-based software design approach.

Recent Enhancements to the System: We solicited feedback from the initial three test users about Java Therapy. All three users desired a greater variety of activities, and detailed on-line feedback about their progress. We thus expanded the Java Therapy system to include an increased library of activities and progress charts. In addition, we incorporated an on-line "To Do List" that can be customized for each user. The "To Do List" is displayed upon logging in (see Figure 2), and shows the user's actual frequency of use of the various activities, compared to the desired frequency of use which can be "prescribed" by a monitoring therapist

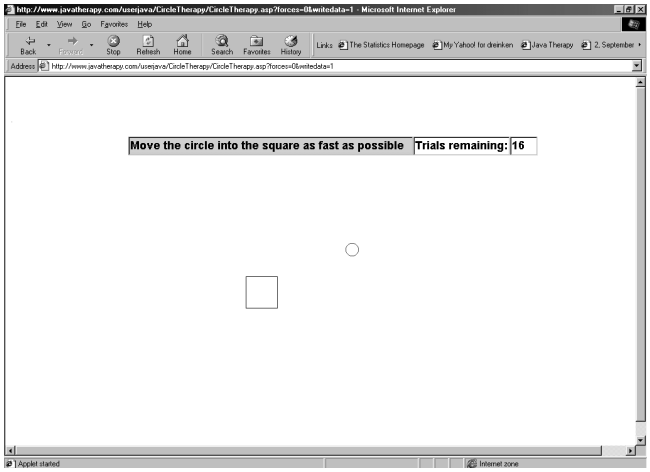

Figure 4: *Prototype therapy game: the user attempts to move the circle into the square as fast as possible, with the square periodically changing location. Movement path and time are stored on the server computer.*

or the user himself or herself.

To summarize the current software status, there are now three categories of activities: status tests, therapy games, and progress reports. Current status tests are:

- A speed test that requires the user to move a cursor into a target, and measures the time to move into the target. This is the prototype therapy game described above without the force feedback. The position of the cursor is sampled and saved every 0.1 seconds, so that the cursor trajectories can be plotted if desired.
- A coordination test that requires the user to trace a figure eight and measures the tracing error. The cursor trajectory is again saved and can be plotted to see the shape of the figure eight the user traced.
- A strength test that requires the user to hold his or her hand as still as possible as the force-feedback joystick tries to move it by applying sinusoidal forces that alternate directions, and measures the total distance moved.
- A finger speed test that requires the user to click the mouse button as many times as possible in ten seconds, and measures the number of clicks.

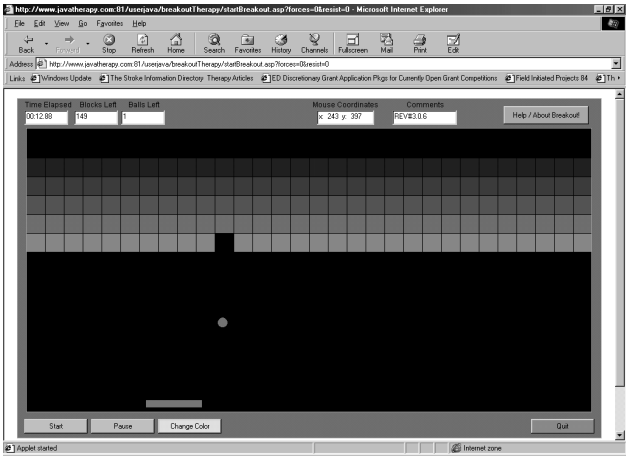

Figure 5: *Breakout therapy game. The joystick will physically assist in playing the game by moving the user's hand to control the paddle and reflect the ball into the bank of targets.*

Current therapy games are:

- A Breakout therapy game (Figure 5), in which the user moves his or her hand to control a paddle on the screen and rebound a moving ball into a bank of targets so that the targets are destroyed. The system keeps track of the number of targets destroyed each time the game is played. If the user is too weak to play the game, the Java Therapy system can physically assist in hand movement using the force feedback joystick. If the user is relatively strong and coordinated, the joystick can resist movement, making the game more challenging.
- A Blackjack therapy game, in which the user clicks buttons in order to play cards.
- An Othello therapy game in which the user must place a checker in appropriate locations on a game board in order to capture checkers.
- A TailGunner therapy game in which the user must move a crosshairs over space ships and pull the joystick trigger to destroy them.

Current *progress reports* are:

- A progress report that informs the user of his or her scores on the status tests or therapy activities immediately upon completion of the activity. The progress report also shows a target score for the user, and compares their current performance to their average

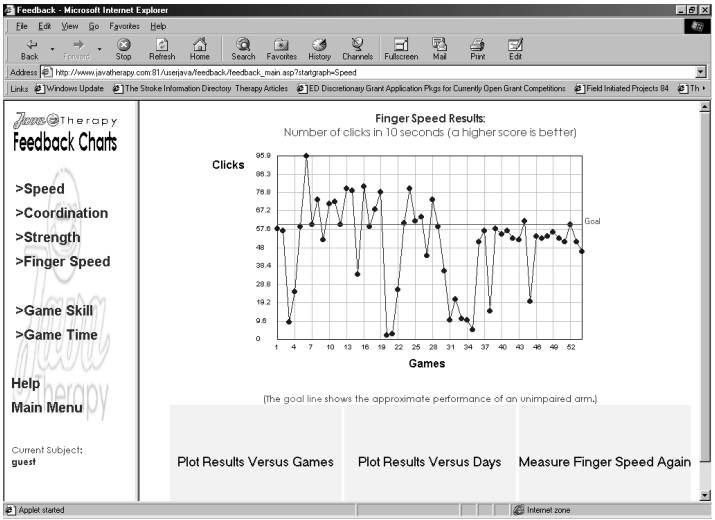

Figure 6: *Progress history for finger speed test*

past performance and their last performance to indicate rehabilitation progress.

- A progress report that displays the user's scores on the status tests or therapy activities as a function of time or as a function of the number of tests or activities performed (Figure 6). The progress report also shows the target score for the user, which can be set by the user or the user's caregiver. This progress report can also be accessed by a caregiver or therapist with a separate user account in order to monitor system usage and rehabilitation progress.
- The "To Do List" that is described above (Figure 2). When the actual frequency for an activity exceeds the desired frequency, the system places encouraging feedback on the "to-do-list" by writing "Good Job!" next to the activity.

Note that our distinction between therapy games and status tests is artificial. Status tests when performed repetitively also comprise a therapeutic activity; conversely, performance on therapy activities is also quantified. However, we find the distinction useful because "therapy games" are in general designed to be more "arcade"-like and engaging, while status tests are simpler and more amenable to quantification.

The enhanced system was implemented using code written in Hypertext Markup Language (HTML), Active Server Pages (ASP), ActiveX, Java, PERL, and CGI. The system is hosted on Internet Information Server 4.0 on WinNT Server and uses a Microsoft Access database and a text-file database. Additionally, we have switched from the Microsoft joystick to the Logitech Wingman Force Feedback joystick as it has better software support and fidelity.

3. System Testing

Several users with movement impairment due to stroke are currently testing the system. Figure 7 shows example data for the speed test for one subject who had used the system for four weeks at the time of writing. This 54 year-old subject had suffered a stroke one year prior to using Java Therapy. He logged in to Java Therapy three times per week from home using a modem. He improved his mean movement speed by approximately 40% over the four-week period, performing over 1600 targeted movements in the speed game alone.

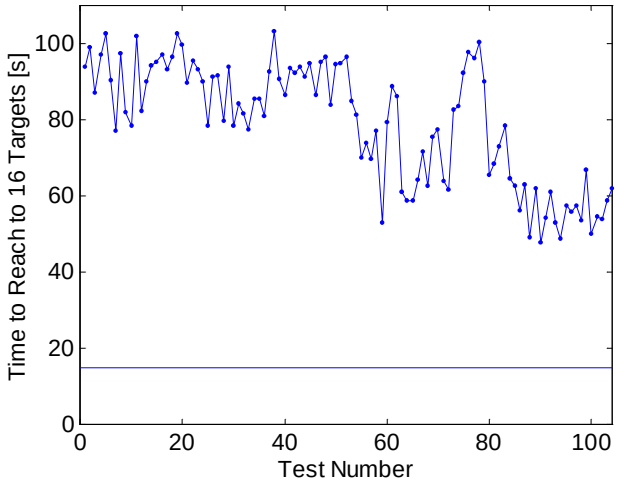

Figure 7: *Performance on the speed test over a four-week period by a chronic stroke subject. The horizontal line shows the approximate average movement time for an unimpaired user.*

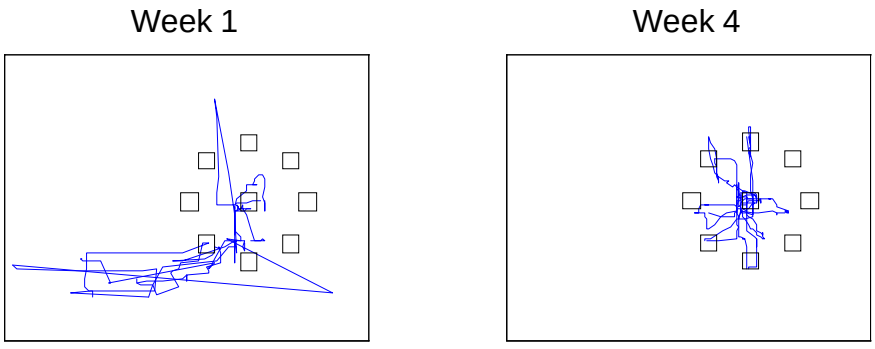

Figure 8: *Example trajectories for speed test during the first and fourth week of Java Therapy usage. The user attempted to move between the center and outer targets (small squares).*

Figure 8 shows examples of hand trajectories from the first and fourth week of therapy. Initially, he exhibited poor control over hand movement trajectories, particularly to targets on the right side of the screen. With repeated practice he moved more directly toward each target. The user's caregiver provided this email feedback in response to the question "Do you have any questions or problems with the system?":

> It all seems to be going well. My husband has worked with it several nights for about an hour each night. Life has been a bit hectic lately, but when we are home he finds time for it. It is good for him in several ways. I'm sure it is good for his arm, but it is also good for him as he feels he is doing something to make progress on the arm. Also it is good for his concentration. He really focuses on what he is doing and this must be good for his mind. I was with him all the time the first few times. After that I have sat at the desk across from him so that I am available, but he has been able to go through most all of the steps himself. He needs me to help get his arm and hand originally in place, but after that he likes to do it himself. It seems to have lots of positive effects in many ways.

4. Discussion

Java Therapy is an affordable, accessible system that allows individuals with movement impairment to organize, practice, and monitor rehabilitation therapy. A key aspect of our future research will be to refine and validate the library of therapy and evaluation activities. We will seek to identify which combination of activities performed at what intensity best promotes movement recovery. In addition to low-cost force feedback joysticks, we plan to investigate other interfaces. A major research challenge will be to design and test input/output devices that can implement the most effective exercises. The Java Therapy software provides an "operating system" for evaluating these devices and exercises. Because it is Web-based, Java Therapy should allow testing of large subject populations, as well as quick and broad dissemination of validated exercise programs.

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