31st Annual International Conference of the IEEE EMBS
Minneapolis, Minnesota, USA, September 2-6, 2009

Design and Implementation of a Home Stroke Telerehabilitation System

William Durfee, James Carey, David Nuckley, Joan Deng

Abstract—**Motor retraining following stroke can occur through intensive, repetitive motion tasks that require concentration to promote new connections in the brain. Conducting intensive, repetitive therapy in the clinic is time consuming for both patient and therapist. A home-based, clinician-directed tracking training system for rehabilitation is presented. Two biofeedback motion training systems have been developed, one for hand and wrist motor relearning and the other for the ankle. The systems include a potentiometer joint sensor, a smart box interface and a laptop host computer. An internet connection allowed for periodic video teleconferencing between patient and therapist. The hand/wrist system was evaluated in a pilot project with 24 subjects. The results demonstrated technical feasibility for the technology. The ankle system is currently undergoing evaluation.**

I. Introduction

STROKE is a significant health problem. Approximately 800,000 people suffer a first or recurrent stroke each year and stroke is the third leading cause of death after heart disease and cancer [1]. On average, every 40 seconds, someone in the U.S. has a stroke. Stroke is the leading cause of serious, long-term disability. About 6.5 million stroke survivors are alive today, an number that is increasing because of improved acute care. In 1999, more than 1.1 million adults reported difficulty with functional limitations resulting from stroke. The direct and indirect cost of stroke in 2009 was $68.9 billion.

A common physical disability following stroke is partial paralysis of a limb, which leads to impairment of basic motor skills in 75% of people with stroke [2]. The wrist, fingers and ankle joints are impaired most often as stroke tends to affect the distal musculoskeletal system. As a result, people with stroke cannot manipulate objects with their hands, which can impair feeding, dressing, handwriting and occupational skills.

New findings in motor learning, neuroplasticity and cell survival following an infarct have lead to a scientific basis for motor retraining following stroke [3, 4]. Studies have demonstrated that motor learning will only occur with voluntary motion where the patient engages the exercise task repeatedly and independently [5, 6]. Repetitive, simple motions are less likely to be effective than complex tasks that involve a high cognitive demand [7].

Conventional physical therapy involves extensive one-on-one interaction with a therapist in the clinic, often for hours at a time several times a week. This paradigm is expensive and presents a transportation challenge for many patients who would prefer to stay at home.

Therefore, there is a need for home-based, clinician-directed therapy that retains the effectiveness of cognitively challenging movement exercises. Our group is developing, testing and refining such a system. In one project, a biofeedback tracking training system for wrist and finger motion was tested in 24 subjects with stroke [8]. In another project, similar feedback technology was developed for ankle motion. In both systems, the therapist could interact with the patient on an occasional basis via an internet video and audio connection. The biofeedback systems depend on sensing active motion. Compared to active robot motor training systems, the passive sensing approach is simple, safe and low cost. The purpose of this paper is to describe the technology and application of the home stroke telerehabilitation systems.

II. Telerehabilitation Technology

A. Finger and Wrist Tracking System

The home tracking system for wrist and hand motion uses custom electrogoniometers to sense bilateral finger and wrist flexion and extension, and includes a microcontroller interface box, a laptop computer running a custom tracking application and a cell phone, web cam and land line telephone for communication with the clinic. An overview of the system is shown in Figures 1 and 2.

Fig. 1. Finger and wrist home stroke telerehabilitation system.

Manuscript received April 23, 2009. This work was supported in part by the National Institutes of Health under Grant R03HD051615

The authors are with the Department of Mechanical Engineering (Durfee) and the Program in Physical Therapy (Carey, Nuckley, Deng), University of Minnesota, Minneapolis MN 55455 USA. Address correspondence to W. Durfee, phone: 612-625-0099, email: wkdurfee@umn.edu.

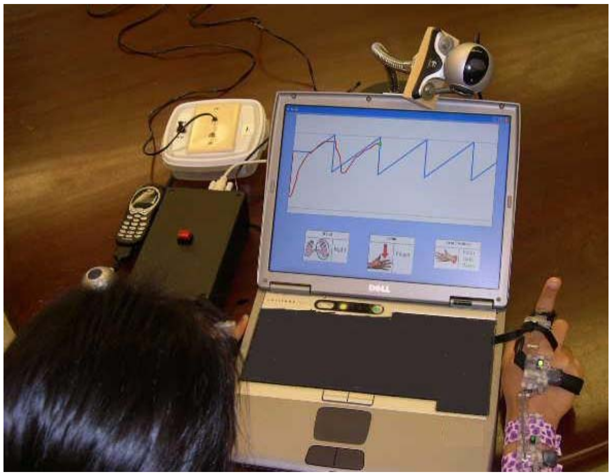

Fig. 2. Finger and wrist system in use.

The electrogoniometers (Figure 3) have three platforms connected by links with a small potentiometer (ETI Systems, SP12S-1K) to sense joint motion. The sensor dimensions were determined by measuring representative male and female hand dimensions and consulting anthropometric reference data. Most patients were able to don and doff the sensor independently.

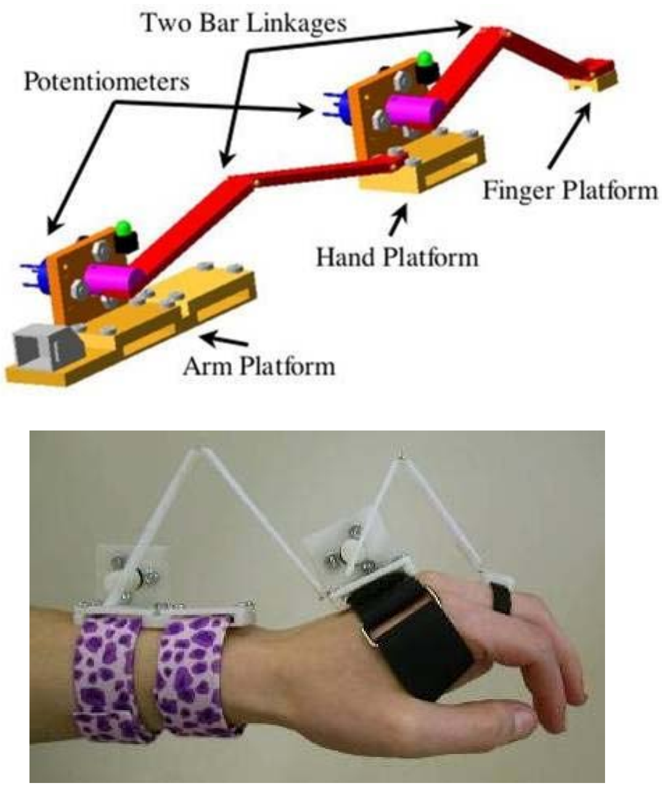

Fig. 3. Electrogoniometer with finger and wrist sensing.

An interface box converted the potentiometer readings into digital data. It includes a microcontroller and a large red button on the top cover. The interface circuitry communicated with the host laptop using an RS-232 serial port. The red button was the primary interface to system operation because the laptop keyboard and mouse were not used.

The tracking application on the host PC was created in Visual Basic 6.0. The computer automatically booted into the software on power up. After a preliminary calibration sequence that determined the subject's active range of motion for that day, the subject was presented with a tracking screen similar to that shown in Figure 4. The icons at the bottom showed the subject the parameters of the next trial, which included side, joint and orientation. After a brief delay, the tracking ball started moving across the screen. Vertical motion of the ball mimicked the joint motion and the task of the subject was to track the target waveform. At the end of the trial, the feedback screen shown in Figure 5 was displayed. The screen gave the subject the tracking accuracy score and, for some trials, helpful feedback on how to improve tracking performance. Eleven metrics related to tracking accuracy were recorded for each trial.

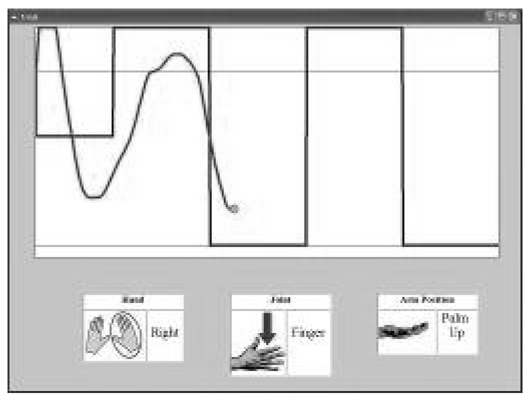

Fig. 4. Sample tracking task screen.

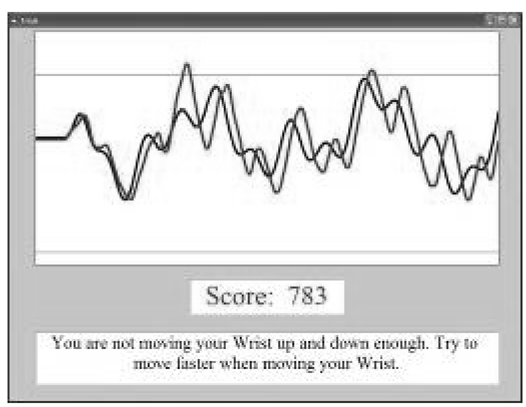

Fig. 5. Sample post-trial performance feedback screen.

The treatment plan called for 180 tracking trials each day for 10 days for a total treatment of 1800 trials. Trials were blocked into sets of three with constant parameters. There were 100 blocks that varied in target wave shape, frequency, duration, joint, hand and hand posture. The mixing of the waveforms and posture forced the patient to concentrate, a prerequisite for effective motor retraining.

Telecommunication occurred between the therapist and the patient every few days. Periodic face-to-face communication is essential for monitoring and motivating the patient to complete the admittedly dull therapy. We assumed that every subject had a land-line telephone, but did not assume broadband internet access. Web cam video and tracking trial data communication were via the land-line and audio communication was by cell phone. Through pilot work we determined that a high quality audio link was essential, but that a low quality video link (color, 128x96, 3 frames per second) was acceptable.

B. Ankle Tracking System

The ankle tracking system uses similar technology to TrackTrain, but with improved features. Figure 6 shows the setup in a subject's home and Figure 7 shows the overall technology architecture.

Fig. 6. Ankle tracking system.

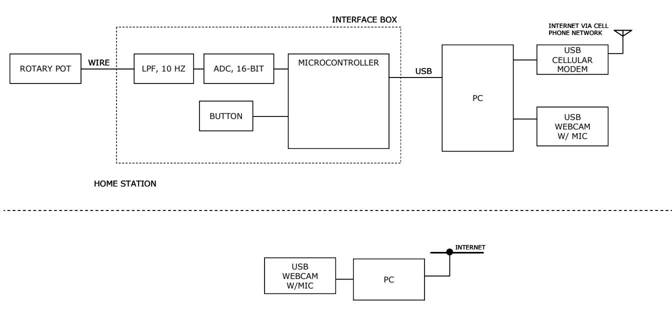

Fig. 7. Ankle tracking system architecture.

The motion sensor has two links with the axis of the potentiometer aligned with the ankle (Figure 8). Figure 8 also shows a Bluetooth wireless version of the sensor. The interface box had one button for system operation and communicated with the host computer over a USB connection, eliminating the need for a separate power supply to feed the electronics. A cellular modem was used to connect to the internet under the assumption that while not everyone has broadband in the home, cell phone coverage is almost universal. For teleconferencing, video and audio was captured with a web cam and Skype was used for the communications channel. In addition, every night at 2 am, the remote system automatically sent that day's tracking performance records to the therapist. An ankle trial with 20 subjects with stroke is in process.

Fig. 8. Wired (left) and wireless (right) versions of the ankle sensor.

III. Results

A. Finger and Wrist Tracking System

The finger and wrist tracking system was placed in the homes of 24 subjects ranging from two to 305 miles from the University of Minnesota plus one at 1,507 miles. Pre and post treatment evaluation instruments included Box and Block, Jebsen Taylor Hand Function, finger range of motion, finger tracking performance and functional MRI to determine the location and level of cortical activation. One half the subjects were in the treatment group and one half were in a control move group that had the same number of trials but no feedback on tracking performance.

Results are reported in [8]. In summary there was improved tracking accuracy, finger range of motion and performance on functional tests. There was also a shift in cortical activity towards the lesioned area. In a surprising result, both the treatment and the control move group had similar functional improvements, despite the move group lacking the concentration component that we hypothesized was necessary for cortical reorganization. We speculate this was because 10 days of treatment was two short to bring out the difference between the two groups.

B. Ankle Tracking System

The clinical trial for ankle tracking calls for 20 subjects with stroke. The treatment intensity is doubled to 20 days of 180 trials per day for a total of 3600 tracking trials, twice that in the finger and wrist study. Berg Balance testing and motion-capture gait analysis were added to the pre- and post-treatment assessment suite. To date, 10 subjects with stroke have completed the treatment.

C. *Human Factors*

In both studies, patients were remarkably receptive to using the equipment. Hardware breakdown was minimal and many problems could be solved by therapist and patient working together during a video conferencing session. However, sensor donning and doffing methods could be improved, which is essential if the subject is to operate the system autonomously.

REFERENCES

[1] AHA, "Heart Disease and Stroke Statistics -- 2009 Update," American Heart Association, 2009.

[2] H. S. Jorgensen, H. Nakayama, H. O. Raaschou, and T. S. Olsen, "Stroke. Neurologic and functional recovery the Copenhagen Stroke Study," pp. 887-906, 1999.

[3] W. J. Chu, G. F. Mason, J. W. Pan, H. P. Hetherington, H. G. Liu, E. C. San Pedro, and J. M. Mountz, "Regional cerebral blood flow and magnetic resonance spectroscopic imaging findings in diaschisis from stroke," *Stroke*, vol. 33, pp. 1243-8, 2002.

[4] D. M. Feeney and J. C. Baron, "Diaschisis," *Stroke*, vol. 17, pp. 817-30, 1986.

[5] R. A. Schmidt and T. D. Lee, *Motor control and learning: A behavioral emphasis, (3rd ed.)*. Champaign, IL: Human Kinetics, 1999.

[6] C. J. Winstein, P. S. Pohl, and R. Lewthwaite, "Effects of physical guidance and knowledge of results on motor learning: Support for the guidance hypothesis.," *Res Q Ex Sport*, vol. 65, pp. 316-323, 1994.

[7] J. R. Carey, E. Bhatt, and A. Nagpal, "Neuroplasticity Promoted by Task Complexity," *Exercise and Sport Science Review*, vol. 33, pp. 24-31, 2005.

[8] J. R. Carey, W. K. Durfee, E. Bhatt, A. Nagpal, S. A. Weinstein, K. M. Anderson, and S. M. Lewis, "Comparison of Finger Tracking Versus Simple Movement Training via Telerehabilitation to Alter Hand Function and Cortical Reorganization After Stroke," *Neurorehabil Neural Repair*, vol. 21, pp. 216-232, 2007.