GESTURE THERAPY
A Low-Cost Vision-Based System for Rehabilitation after Stroke

L. Enrique Sucar[1], Ron S. Leder[2], David Reinkensmeyer[3], Jorge Hernández[4], Gidardo Azcárate[5]
Nallely Casteñeda[6] and Pedro Saucedo[7]
[1]Departamento de Computación, INAOE, Tonantzintla, Puebla, México
esucar@inaoep.mx
[2]División de Ingeniería Eléctrica, UNAM, México D.F., México
rleder@ieee.org
[3]Department of Mechanical and Aerospace Engineering, UC Irvine, USA
dreinken@uci.edu
[4]Unidad de Rehabilitación, INNN, Mexico D.F., Mexico
jhfranco@medicapolanco.com
[5]ITESM Campus Cuernavaca, Morelos, México
A01125613@itesm.mx
[6]Unidad de Rehabilitación, INNN, Mexico D. F., Mexico
alvacasana@yahoo.com.mx
[7]Universidad Anáhuac del Sur, Mexico D.F., Mexico
saucedouribe@gmail.com

Keywords: Rehabilitation, stroke, therapeutic technology.

Abstract: An important goal for rehabilitation engineering is to develop technology that allows individuals with stroke to practice intensive movement training without the expense of an always-present therapist. We have developed a low-cost, computer vision system that allows individuals with stroke to practice arm movement exercises at home or at the clinic, with periodic interactions with a therapist. The system intgrates a web-based system for facilitating repetitive movement training, with state-of-the art computer vision algorithms that track the hand of a patient and obtain its 3-D coordinates, using two inexpensive cameras and a conventional personal computer. An initial prototype of the system has been evaluated in a pilot clinical study with positive results.

1 INTRODUCTION

Each year in the U.S. alone over 600,000 people survive a stroke (ASA 2004), and similar figures exist in other countries. Approximately 80% of acute stroke survivors lose arm and hand movement skills. Movement impairments after stroke are typically treated with intensive, hands-on physical and occupational therapy for several weeks after the initial injury. Unfortunately, due to economic pressures on health care providers, stroke patients are receiving less therapy and going home sooner. The ensuing home rehabilitation is often self-directed with little professional or quantitative feedback. Even as formal therapy declines, a growing body of evidence suggests that both acute and chronic stroke survivors can improve movement ability with intensive, supervised training. Thus, an important goal for rehabilitation engineering is to develop technology that allows individuals with stroke to practice intensive movement training without the expense of an always-present therapist.

We have developed a prototype of a low-cost, computer vision system that allows individuals with stroke to practice arm movement exercises at home or at the clinic, with periodic interactions with a therapist. The system makes use of our previous work on a low-cost, highly accessible, web-based system for facilitating repetitive movement training, called “Java Therapy”, which has evolved into T-WREX (Fig. 1) (Reinkensmeyer 2002 and Sanchez 2006). T-WREX provides simulation activities relevant to daily life. The initial version of Java Therapy allowed users to log into a Web site, perform a customized program of therapeutic activities using a mouse or a joystick, and receive quantitative feedback of their progress. In preliminary studies of the system, we found that stroke subjects responded enthusiastically to the quantitative feedback provided by the system. The use of a standard mouse or joystick as the input device also limited the functional relevance of the system. We have developed an improved input device that consists of an instrumented, anti-gravity orthosis that allows assisted arm movement across a large workspace. However, this orthosis costs about $4000 to manufacture, limiting its accessibility. Using computer vision this system becomes extremely attractive because it can be implemented with low cost (i.e. using an inexpensive camera and conventional computer).

For "Gesture Therapy" we combine T-WREX with state-of-the art computer vision algorithms that track the hand of a patient and obtain its 3-D coordinates, using two inexpensive cameras (web cams) and a conventional personal computer (Fig. 2). The vision algorithms locate and track the hand of the patient using color and motion information, and the views obtained from the two cameras are combined to estimate the position of the hand in 3-D space. The coordinates of the hand (X, Y, Z) are sent to T-WREX so that the patient interacts with a virtual environment by moving his/her impaired arm, performing different tasks designed to mimic real life situations and thus oriented for rehabilitation. In this way we have a low-cost system which increases the motivation of stroke subjects to follow their rehabilitation program, and with which they can continue their arm exercises at home.

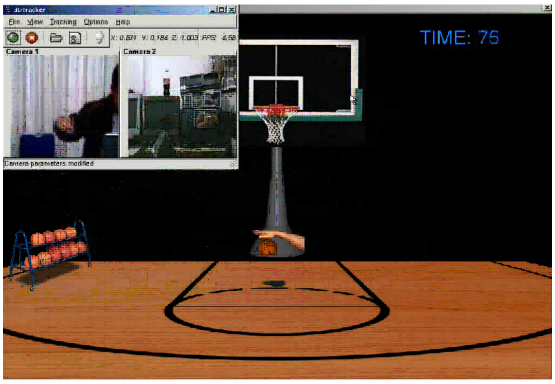

Figure 1: Screen shot of T-WREX. Arm and hand movements are focused as a mouse pointer to activate an object in the simulation. In this case a hand interacts with a basketball. The upper left insert shows the camera views, frontal and side, of the patient's hand tracked by the system.

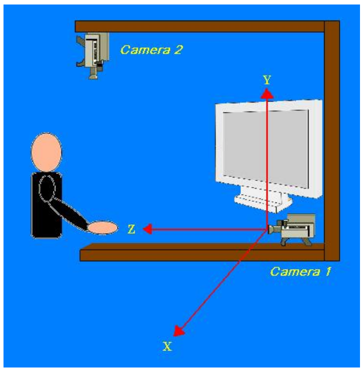

Figure 2: Set up for the Gesture Therapy system. The patient is seated in front of a table that serves as a support for the impaired arm, and its movements are followed by two cameras. The patient watches in a monitor the simulated environment and his/her control of the simulated actuator.

A prototype of this system has been installed at the rehabilitation unit at the National Institute of Neurology and Neurosurgery (INNN) in Mexico City, and a pilot study was conducted with a patient diagnosed with ischemic stroke, left hemi paresis, with a time of evolution of 4 years. After 6 sessions with Gesture Therapy, the results based on the therapist and patient opinions are positive, although a more extensive controlled clinical trial is required to evaluate the impact of the system in stroke rehabilitation. In this paper we describe the Gesture Therapy system and present the results of the pilot clinical study.

2 METHODOLOGY

Gesture Therapy integrates a simulated environment for rehabilitation (Java Therapy) with a gesture tracking software in a low-cost system for rehabilitation after stroke. Next we describe each of these components.

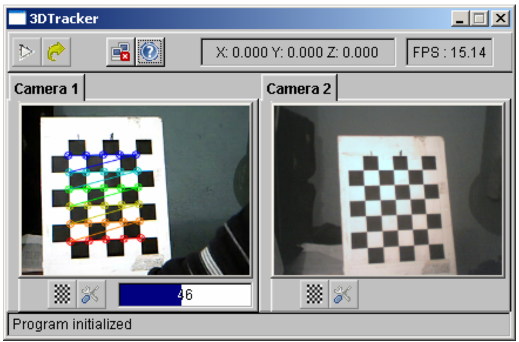

Figure 3: Reference pattern used for obtaining the intrinsic parameters of each camera (camera 1 and 2).

2.1 Java Therapy/T-WREX

The Java Therapy/T-WREX web-based user interface has three key elements: therapy activities that guide movement exercise and measure movement recovery, progress charts that inform users of their rehabilitation progress, and a therapist page that allows rehabilitation programs to be prescribed and monitored

The therapy activities are presented in the software simulation like games and the system configuration allows therapists to customize the software to enhance the therapeutic benefits for each patient, by selecting a specific therapy activity among others in the system

The therapy activities were designed to be intuitive even for patients with minimal cognitive or perceptual problems to understand. These activities are for repetitive daily task-specific practice and were selected by its functional relevance and inherent motivation like grocery shopping, car driving, playing basketball, self feeding, etc.

Additionally, the system gives objective visual feedback of patient task performance, and patient progress can be illustrated easily by the therapist by a simple statistical chart. The visual feedback has the effect of enhancing motivation and endurance along the rehabilitation process by patients awareness of his/her progress.

2.2 Gesture Tracking

Using two cameras (stereo system) and a computer, the hand of the user is detected and tracked in a sequence of images to obtain its 3-D coordinates in each frame, which are sent to the T-WREX environment. This process involves several stages:

- Calibration,
- Segmentation,
- Tracking,
- 3-D reconstruction.

Next we describe each stage.

2.2.1 Calibration

To have a precise estimation of the 3-D position in space of the hand, the camera system has to be calibrated. The calibration consists in obtaining the intrinsic (focal length, pixel size) and extrinsic (position and orientation) parameters of the cameras. The intrinsic parameters are obtained via a reference pattern (checker board) that is put in front of each camera, as shown in figure 3.

The extrinsic parameters are obtained by giving the system the position and orientation of each camera in space with respect to a reference point, see figure 2. The reference point could be the lens of one of the cameras, or an external point such as a corner of the table. The colors on the checker board pattern and the status bar shown in figure 3 above indicate the progress of the calibration process.

Note that the calibration procedure is done only once and stored in the system, so in subsequent sessions this procedure does not need to be repeated, unless the cameras are moved or changed for other models.

2.2.2 Segmentation

The hand of the patient is localized and segmented in the initial image combining color and motion information. Skin color is a good clue to point potential regions where there is a hand/face of a person. We trained a Bayesian classifier with many (thousand) samples of skin pixels in HSV (hue, saturation, value), which is used to detect skin pixels in the image. Additionally, we use motion information based on image subtraction to detect moving objects in the images, assuming that the patient will be moving his impaired arm. Regions that satisfy both criteria, skin color and motion, are extracted by an intersection operation, and this region corresponds to the hand of the person. This segment is used as the initial position of the hand for tracking it in the image sequence, as described in the next section. This procedure is applied to both images, as illustrated in figure 4.

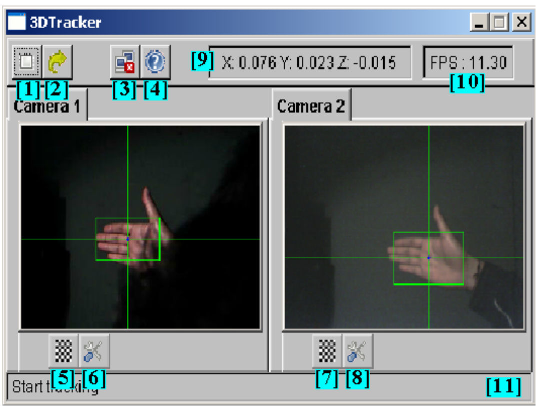

Figure 4: Hand detection and segmentation in both images. The approx. hand region is shown as a rectangle, in which the center point is highlighted, used later for finding the 3-D coordinates.

The system can be confused with objects that have a similar color as human skin (i.e wood), so we assume that this does not occur. For this it is recommended that the patient uses long sleeves, and to cover the table and back wall with a uniform cloth in a distinctive color (like black or blue). It is also recommended that the system is used indoors with artificial lighting (white). Under these conditions that system can localize and track the hand quite robustly in real time.

2.2.3 Tracking

Hand tracking is based on the *Camshift* algorithm (Bradski, 1998). This algorithm uses only color information to track an object in an image sequence. Based on an initial object window, obtained in the previous stage, Camshift builds a color histogram of the object of interest, in this case the hand. Using a search window (define heuristically according to the size of the initial hand region) and the histogram, Camshift obtains a probability of each pixel in the search region to be part of the object, and the center of the region is the "mean" of this distribution. The distribution is updated in each image, so the algorithm can tolerate small variation in illumination conditions.

In this way, the 2-D position of the hand in each image in the video sequence is obtained, which corresponds to the center point of the color distribution obtained with Camshift. The 3-D coordinates are obtained by combining both views, as described in the next section.

2.2.4 3-D Reconstruction

Based on the 2-D coordinates of the center point of the image region in each image, the 3-D coordinates are obtained in the following way. For each image, a line in 3-D space is constructed by connecting the center of the hand region and the center of the camera lens, based on the camera parameters. This is depicted in figure 5. Once the two projection lines are obtained, their intersection provides the coordinates in 3-D (*X, Y, Z*).

Thus, we have the 3-D position of the hand for each processed image pair (about 15 frames per second in a standard PC), which are sent to T-WREX so that the patient can interact with the virtual environments.

3 PILOT STUDY

We performed a pilot study with one patient using "Gesture Therapy" at the National Institute for Neurology and Neurosurgery (INNN) in Mexico City. The purpose of this pilot study was to improve the protocol for a larger clinical trail with Gesture Therapy, anticipating potential problems and gaining experience using the technology in the hospital

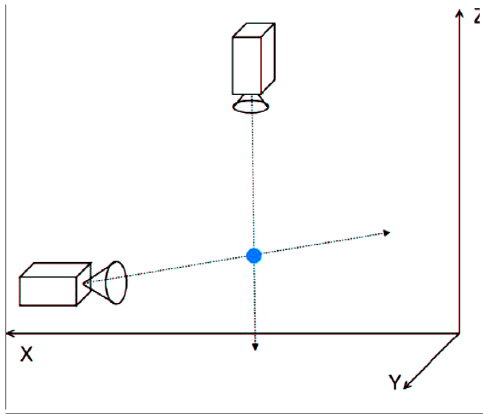

Figure 5: Estimation of the 3-D position of the hand by intersecting the projection lines obtained from the images.

setting.

The patient was diagnosed with ischemic stroke, left hemi paresis, with a time of evolution of 4 years. An evaluation with the Fugl-Meyer (Fugl-Meyer, 1975) scale was performed at the start and end of the study.

The patient used Gesture Therapy for 6 sessions, between 20 and 45 minutes each session. The main objective of the exercises was the control of the distal portion of the upper extremity and hand. The patient performed pre exercises for stretching, relaxation, and contraction of the fingers and wrist flexors and extensors. The patient performed several of the simulated exercises in the virtual environment, increasing in difficulty as the sessions progressed (clean stove, clean windows, basketball, paint room, car race).

After the 6 sessions the patient increased his capacity to voluntarily extend and flex the wrist through relaxation of the extensor muscles. He also tried to do bimanual activities (such as take and throw a basket ball) even if he maintained the affected left hand closed; he increased use of the affected extremity to close doors.

In the therapist's opinion: "The GT system favours the movement of the upper extremity by the patient. It makes the patient maintain the control of his extremity even if he does not perceive it. GT maintains the motivation of the patient as he tries to perform the activity better each time (more control in positioning the extremity, more speed to do the task, more precision). This particular patient gained some degree of range of movement of his wrist. There are still many problems with the fingers flexor synergy, but he feels well and motivated with his achievements. It is also important to note the motivation effect the system has on patient endurance to complete the treatment until the last day by increasing the enthusiasm of the patient in executing the variety of rehabilitation exercises."

In the patient's opinion: "At the beginning I felt that my arm was too "heavy", and at the shoulder I felt as if there was something cutting me, now I feel it less heavy and the cutting sensation has also been reduced."

An "analogical visual scale" in the range 1-10 (very bad, ..., excellent) was applied, asking the patient about the treatment based on GT, he gave it a 10. Asked about if he will like to continue using GT, his answer was "YES".

The Fugl-Meyer scale (3 points increase) was not sufficiently sensitive to detect the clear clinical and subjective improvement in the patient.

4 CONCLUSIONS AND FUTURE WORK

This single case shows the importance of motivation in rehabilitation. Involving the patient in simulated daily activities helps the psychological rehabilitation component as well. The potential ease of use, motivation promoting characteristics, and objective quantitative potential are obvious advantages to this system. The patient can work independently with reduced therapist interaction. With current technology the system can be adapted to a portable low-cost device for the home including communications for remote interaction with a therapist and medical team.

It is possible to extend the system to a full arm tracking, including wrist, hand and fingers for more accurate movements. Movement trajectories can be compared and used to add a new metric of patient progress. To make the system easier to use a GUI tool is planned for system parameters configuration, including the camera. Future work includes more games to increase the variety of therapy solutions and adaptability to patient abilities, so that a therapist or patient can match the amount of challenge necessary to keep the rehabilitation advancing.

In the current low-cost, vision-based system the table top serves as an arm support for 2D movement until the patients are strong enough to lift their arms into 3D. Extending the system to wrist, hand, and finger movement is planned to make a full superior extremity rehabilitation system.

Wrist accelerometers can be used to increase the objectivity of clinical studies in addition to subjective reports of patients and caregivers; especially when the patient spends less time in the clinic. (Uswatte 2006). fMRI of patients' brains, pre and post training, are planned for increasing our understanding of the biological basis for rehabilitation (Johansen-Berg 2002).

ACKNOWLEDGEMENTS

This work was supported in part by a grant from UC-MEXUS/CONACYT.

REFERENCES

American Stroke Association, 2004. Retrieved July 10, 2007 from http://www.strokeassociation.org.

G.R. Bradski, 1998. Computer vision face tracking as a component of a perceptual user interface. In *Workshop on Applications of Computer Vision,* pp. 214-219.

A. R. Fugl-Meyer, L. Jaasko, I. Leyman, S. Olsson, and S. Steglind, 1975. The post-stroke hemiplegic patient: a method for evaluation of physical performance. In *Scand J Rehabil Med,* vol. 7, pp. 13-31.

D. Reinkensmeyer, C. Pang, J. Nessler, and C. Painter, 2002. Web-based telerehabilitation for the upper-extremity after stroke. In *IEEE Transactions on Neural Science and Rehabilitation Engineering,* vol. 10, pp. 1-7.

R. J. Sanchez, J. Liu, S. Rao, P. Shah, R. Smith, T. Rahman, S. C. Cramer, J. E. Bobrow, and D. Reinkensmeyer, 2006. Automating arm movement training following severe stroke: Functional exercise with quantitative feedback in a gravity-reduced environment. In *IEEE Trans. Neural. Sci. Rehabil. Eng*., vol. 14(3), pp. 378-389.D. Reinkensmeyer, S. Housman, Vu Le, T. Rahman and R. Sanchez, 2007. Arm-Training with T-WREX After Chronic Stroke: Preliminary Results of a Randomized Controlled Trial. In *ICORR 2007, 10th International Conference on Rehabilitation Robotics,* Noordwijk.

D. Reinkensmeyer and S. Housman, 2007. If I can't do it once, why do it a hundred times?: Connecting volition to movement success in a virtual environment *motivates people to exercise the arm after stroke.* In *IWVR 2007*

G, Uswatte, C. Giuliani, C. Winstein, A. Zeringue, L. Hobbs, SL Wolf, 2006. Validity of accelerometry for monitoring real-world arm activity in patients with subacute stroke: evidence from the extremity constraint-induced therapy evaluation trial. *Arch Med Rehabil:* 86:1340-1345.

H. Johansen-Berg, H. Dawes, C. Guy, S.M. Smith, D.T. Wade and P.M. Matthews, 2002 Correlation between motor improvements and altered fMRI activity after rehabilitative therapy. *Brain Journal:* 125, 2731-2742