

Clinical Evaluation of a Low-Cost Alternative for Stroke Rehabilitation

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Abstract—Stroke is the main cause of disabilities in the world and is typically treated with intensive, hands-on physical and occupational therapy for several weeks after the initial injury. However, due to economic pressures, stroke patients are receiving less therapy and going home sooner, so the potential benefit of the therapy is not completely realized. Thus, it is important to develop rehabilitation technology that allows individuals who had suffered a stroke to practice intensive movement training without the expense of an always-present therapist. Although several robotic devices have been developed for stroke rehabilitation, these are too expensive for use at home or in small clinics. We have developed a low-cost alternative that allows stroke survivors to practice arm movement exercises at home or at the clinic, with periodic interactions with a therapist. The system integrates a virtual environment for facilitating repetitive movement training, with computer vision algorithms that track the hand of a patient, using an inexpensive camera and a conventional personal computer. This system, called *Gesture Therapy*, has been evaluated in a controlled clinical trial at a hospital in Mexico City, comparing it with conventional occupational therapy. The results show that both treatments improve the functionality of the affected upper extremity, with not significant difference between them. However, the patients that used the virtual environment have a greater motivation and attachment to the treatment, which in the long term are decisive for maximal recovery.

I. INTRODUCTION

Stroke is the main cause of disabilities in the world; in the U.S. alone the figure is over 700,000 survivors per year needing therapy, it is the third leading cause of death in America and the No. 1 cause of adult disability [1]. 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. Although there are some recent developments of robotic systems for rehabilitation [2], these are too expensive for their use at home or in small clinics. For example, the *Armeo* arm exoskeleton device has a cost of approx. \$40,000 USD [3]. Thus, a low cost alternative is required for home therapy.

We have developed a low-cost vision-based system for rehabilitation after stroke, called “*Gesture Therapy*” [4]. The objective of the system is to allow 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 a virtual environment for facilitating repetitive movement training that provides simulation activities relevant to daily life. A low-cost camera is used for tracking the hand of the patient. The vision algorithms locate and track a ball in the hand of the patient using color and texture information, and based on the apparent diameter of the ball, estimate its 3-D position in space. The coordinates of the hand are sent to the simulator 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 effective rehabilitation. The estimated cost of the system is in the order of \$2,000 USD, including the cost of a personal computer.

A prototype of the *Gesture Therapy* system has been installed at the rehabilitation unit at the National Institute of Neurology and Neurosurgery (INNN) in Mexico City. A comparative clinical evaluation has been conducted at INNN with 22 stroke patients, 11 used *Gesture Therapy* and 11 received conventional therapy. Each patient received 15 therapy sessions, 3 times per week, in the period from August to December 2008. The clinical evaluation was done using the Fugl-Meyer and Motricity Index scales, and also a Intrinsic Motivation scale was administered at the end of the treatment. The results show that both groups have a significant improvement according to the two standard clinical scales, but there is no significant difference between both groups. However, according to the Intrinsic Motivation scale, a stronger motivation and attachment to the treatment is observed for the patients that used *Gesture Therapy*. We consider that this is an important result since long term motivation and attachment are decisive for maximal recovery.

The rest of the paper is organized as follows. Next we describe the *Gesture Therapy* system, and in Section III the clinical evaluation and results. We conclude with a summary

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and directions for future work.

II. GESTURE THERAPY

Gesture Therapy integrates a simulated environment for rehabilitation with a gesture tracking software in a low-cost system for rehabilitation after stroke. The movement of the patient's affected hand is tracked based on an image sequence obtained by a low-cost camera. The tracker estimates the 3-D coordinates of the hand in each frame, and sends this information to the simulated environment, so that the patient can interact with the *games* and observe the results in the screen. The physical system has 3 main elements: (a) a personal computer, (b) a web cam, and (c) a hand grip. The personal computer is used to run the software for both, the simulated environment and the visual tracker, and to display the interface of the games to the user via a monitor. The web cam follows the movements of the patient by tracking a colored ball attached to the grip. The grip is attached to the hand of the patient if necessary; it is currently used to follow the motion of the hand, and in the future it will be used to measure hand grasp strength. Next we describe the simulated environment and then the tracking subsystem.

A. Simulated environment

The T-WREX [2] subsystem 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. These activities were designed to be intuitive even for patients with minimal cognitive or perceptual problems to understand. The simulated 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. 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. It also provides facilities to define the range of motions of the hand of the patient, so it can be adapted according to each patient's needs and progress in the therapy.

Additionally, the system gives objective visual feedback of patient task performance as well as entertainment. Patient progress is illustrated using simple statistical charts. The visual feedback has the effect of enhancing motivation and endurance along the rehabilitation process by a patient's awareness of his/her progress, as we found in our clinical results.

There are several simulation/games in the current prototype, including: Basketball, Car Racing, Wall Painting, Supermarket Shopping, and Cooking Eggs, among others. In Fig. 1 a few examples of different rehabilitation games are shown. Figure 2 shows an example of the feedback given to the patient in the *Basketball* game.

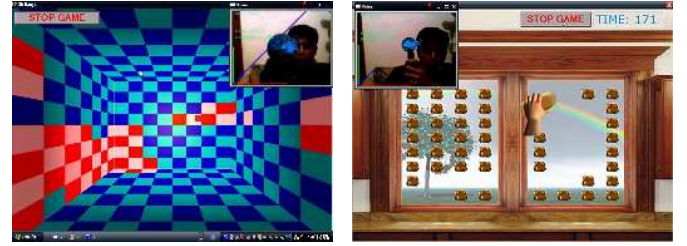


Fig. 1. Examples of different games in the simulated environment. **Left:** painting the wall. **Right:** cleaning the window. The inserts show an image from the visual tracker, indicating the different estimates of the position of the ball (*particles*) as dots over the sphere.

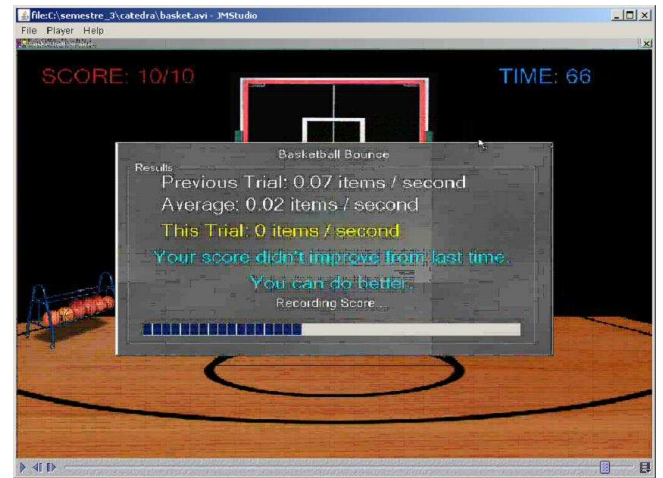


Fig. 2. Feedback given to the patient after playing the basketball game.

B. Monocular tracker

Based on a single low-cost camera and a computer, the hand of the user (via a specially colored ball attached to it) is detected and tracked in a sequence of images to obtain its 3-D coordinates in each frame, which are sent to the simulated environment. First the object is tracked in 2-D and then the third coordinate (depth) is estimated.

Tracking the object in 2-D is based on particle filters [5]. Initially, the object to be tracked is captured (in our experiments a blue ball), and color and texture histograms are obtained from the object region in the image. Color and texture information are combined with a simple motion model to track the position of the ball in the image using particle filters, and the 2-D position, (x, y) , is estimated as the mean of the particles. The color observation model is based on the HSV color representation, while the texture model uses an edge orientation histogram. Both estimates are combined by a simple multiplication, assuming conditional independence.

The variance of the distribution of the particles is used to estimate the distance of the object to the camera, that is the depth, z . Finally the tracker reports the existence of the object and its position in space, (x, y, z) , to the simulated environment.

An image that illustrates the visual tracker is shown in figure 3. To evaluate the precision of the monocular 3-



Fig. 3. An example of visual tracking of a blue ball. The dots over the ball represent the different estimates of the ball position (x, y) given by the particle filter. The axis represent the ball position in 3-D; the horizontal axis is the x coordinate, the vertical is y , and the third one at approx. 45 degrees represents the depth or z .

D tracker we compared it with a stereo system [6]. The tests were performed in an indoor environment with artificial lighting. The stereo system was used as a reference system for measuring the accuracy of the monocular tracking system. Various trajectories were made using a blue colored ball. We observed a close agreement between both trackers. In the depth estimation there is some difference due to a scaling factor in the monocular tracker, issue that can be addressed by a simple depth calibration of the monocular system. However, for this application a precise estimation of absolute depth is not critical.

III. CLINICAL STUDY

A. Methodology

An initial clinical evaluation of the Gesture Therapy system has been conducted at the Rehabilitation Unit of the National Institute for Neurology and Neurosurgery (INNN) in Mexico City. It is a longitudinal and comparative study with 22 patients that have suffered a stroke. All the patients have an evolution of 6 months or more after the stroke. The patients were divided randomly into two groups; a control group with 11 patients, and a study group with 11 patients. The control group received conventional occupational therapy, while the study group used the Gesture Therapy system guided by a therapist. There were in total 10 female patients (45%) and 12 male patients (55%); the age range is from 43 to 68 years old with an average of 52.37 for the control group, and from 39 to 68 years old with an average of 50.83 for the study group. The mean evolution time after the stroke is 25.7 months for the control group, and 22.08 months for the study group. Both groups received treatment for 15 sessions, about 60 minutes each, during 5 weeks, 3 sessions per week.

The occupational therapy consisted on different exercises of the affected upper extremity guided by a therapist, using didactic material such as cones, balls, etc.

For the patients using Gesture Therapy, before each session a calibration procedure is done to define the range of motions of the hand (in x, y, z) according to the patient. Then the therapist determines which games to use for each patient according to goals established in a previous clinical evaluation. The virtual games used for all the patients were:

- Shopping in the supermarket.
- Making breakfast.
- Playing basketball.
- Cleaning the windows.
- Cleaning the stove.
- Painting the walls.
- Preparing a hot dog.
- Driving in the highway.

The impact of the therapy for both groups was evaluated using 3 different scales: (i) the Fugl-Meyer (FM) scale [7], (ii) the Motricity Index [8], and an Intrinsic Motivation Survey [9]. The Fugl-Meyer and Motricity Index scales were applied before and after the therapy to each patient in both groups; while the Intrinsic Motivation Scale was applied to each patient of both groups at the end of the clinical study¹.

Next we summarize the results of this study.

B. Results

We first analyzed the evolution of both groups of patients in terms of the Fugl-Meyer scale and Motricity Index. Both groups present a significant improvement (according to the Wilcoxon statistical test with $p < 0.5$) after the 15 therapy sessions in terms of motor and functional recovery of the impaired arm. The Motricity Index shows a significant improvement in both groups; increasing from 42.1% to 52.6% in the control group, and from 32.33% to 52.91% in the study group. There is also a notable improvement in Fugl-Meyer scale, from 18 to 26.3 in the control group, and from 13.41 points to 31.91 points in the study group.

We then compared both groups in terms of both, the Motricity Index and the Fugl-Meyer scale. There is an apparently greater improvement in the study group for both scales; with a difference of 30.58% vs. 20.5% for the Motricity Index, and 18.5 points vs. 8.3 for the Fugl-Meyer scale. However, these differences are not statistically significant (Wilcoxon statistical test with $p < 0.5$).

The motivation survey applied to each patient after the treatment evaluates the following aspects:

- Interest and enjoyment of the treatment.
- Effort and importance of the treatment.
- Pressure or tension caused by the treatment.
- Utility of the treatment.
- Pain caused by the treatment.
- Perception of challenge by the patient.

The average results of the clinical survey for the study and control groups, for each aspect, are summarized in table I. The results of this survey show that the study group enjoyed

¹Given that the evaluation was done by the same therapist that guided the patients, in this study the clinical assessments were not performed by a blinded therapist.

TABLE I
AVERAGE RESULTS FOR THE MOTIVATION SURVEY.

Aspect	Study Group	Control Group
Interest	13	4
Competence	6	4
Effort	19	15
Pressure	5	5
Utility	18	6
Pain	3	2

more and have a greater interest in the Gesture Therapy system, as well as a greater perception in terms of effort and utility, while the aspects related to pressure and pain were similar for both groups.

C. Discussion

Based on this first clinical study, we conclude that we can not report a significant advantage of Gesture Therapy over conventional occupational in therapy in terms of the motor and functional recovery of the affected upper extremity in the short term. There may be some advantage with Gesture Therapy, so we are continuing clinical studies to reach a more definite conclusion.

According to the motivation survey and feedback from the therapists, a stronger motivation and attachment to the treatment is observed for the patients that used Gesture Therapy. This is an important advantage for Gesture Therapy, as in the long term motivation and attachment are decisive for maximal recovery.

The T-Wrex exercises are designed to be similar to *activities of daily living*, however we have not evaluated the impact of GT in this aspect.

IV. CONCLUSIONS

We have developed Gesture Therapy, a low-cost 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 integrates a virtual environment for facilitating repetitive movement training, with computer vision algorithms that track the hand of a patient, using an inexpensive camera and a conventional personal computer.

A prototype of the Gesture Therapy system has been installed at the rehabilitation unit of the INNN hospital in Mexico City. A first clinical study shows similar results in rehabilitation in terms of standard clinical scales for patients using Gesture Therapy compared to those receiving conventional therapy. However, according to a motivation survey and feedback from the therapists, a stronger motivation and attachment to the treatment is observed for the patients that used Gesture Therapy, which is considered an important factor for maximal recovery. We are continuing the clinical study with more patients and expect to report more conclusive results in the near future.

A. Current and Future Work

One of the objectives of this work is to develop a rehabilitation system that can be used at home without the need

of having an always-present therapist. For this, two other aspects should be considered. First, the system should be able to evaluate objectively the progress of the patient so it can provide feedback and motivate him to continue the therapy. Second, the system should adapt according to the progress of the patient so it requires the right amount of effort. We are currently working in both areas.

We have developed a technique to evaluate how well did a patient do certain movements, to quantify her progress and provide quantitative feedback [10] based on hidden Markov models. We are also developing a module that can adjust the level of difficulty of the simulated environment based on the progress of the patient. The idea is to use partially observable Markov decision processes (POMDPs) based on the work of J. Hoey et al. [11]. In the future we plan to integrate both components; the feedback mechanism and the automatic adjustment, to the Gesture Therapy system.

To have a more comprehensive evaluation of the effects of rehabilitation in the long term, we are also developing a system based on wrist worn actigraphy to capture objective measures, patient compliance, and reduce reliance on anecdotal reports of behavior profiles between clinic visits.

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