Gesture Therapy: a Clinical Evaluation

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***Abstract*— Each year millions of people in the world survive a stroke. Movement impairments after stroke are 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. 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 integrates a virtual environment for facilitating repetitive movement training, with computer vision algorithms that track the hand of a patient and obtain its 3-D coordinates, using an inexpensive camera and a conventional personal computer. The system, called "Gesture Therapy", is being evaluated in a controlled clinical trial at a hospital in Mexico City. In this paper we describe the system and discuss the results of a first clinical evaluation.**

I. INTRODUCTION

Each year millions of people in the world survive a stroke, in the U.S. alone the figure is over 600,000 people per year [10], [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 their are some recent developments of robotic systems for rehabilitation [6], these are too expensive for their use at home or in small clinics. Thus, a low cost alternative is required.

We have developed a low–cost vision–based system for rehabilitation after stroke, called "Gesture Therapy" [12]. 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 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 motion information, and based on the apparent size of the ball, they 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 rehabilitation.

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 clinical study is under way with 15 stroke patients, 8 used Gesture Therapy and 7 received conventional therapy. The results after 20 therapy sessions show that both groups have a significant improvement according to two standard clinical scales, with no significant difference between both groups. Additionally, 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. This preliminary results suggest that Gesture Therapy is as effective clinically as the conventional occupational therapy, and more engaging for the patients.

The rest of the paper is organized as follows. Next we summarize related work and then we describe the Gesture Therapy system. In section IV the clinical evaluation and results are presented. Section V describes our current work in developing tools for giving feedback to the patients and adjusting automatically the exercises, and we conclude with a summary.

II. RELATED WORK

Previous work on rehabilitation technology is mostly on robotic systems, such as [6]; however, these are too expensive for their use at home or in small clinics, and require the assistance of a therapist.

There is some previous work on using vision and other low cost sensors to track the movement of the arm for stroke rehabilitation. Zhou and others [15] develop a system that uses an inertial sensor attached to the arm of the patient, and

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This work was supported in part by SALUD/CONACYT grant No. SALUD-2007-C01-70074; and under a grant from the Department of Education NIDRR grant number H133E070013. However, its contents do not necessarily represent the policy of the Department of Education, and you should not assume endorsement by the Federal Government.

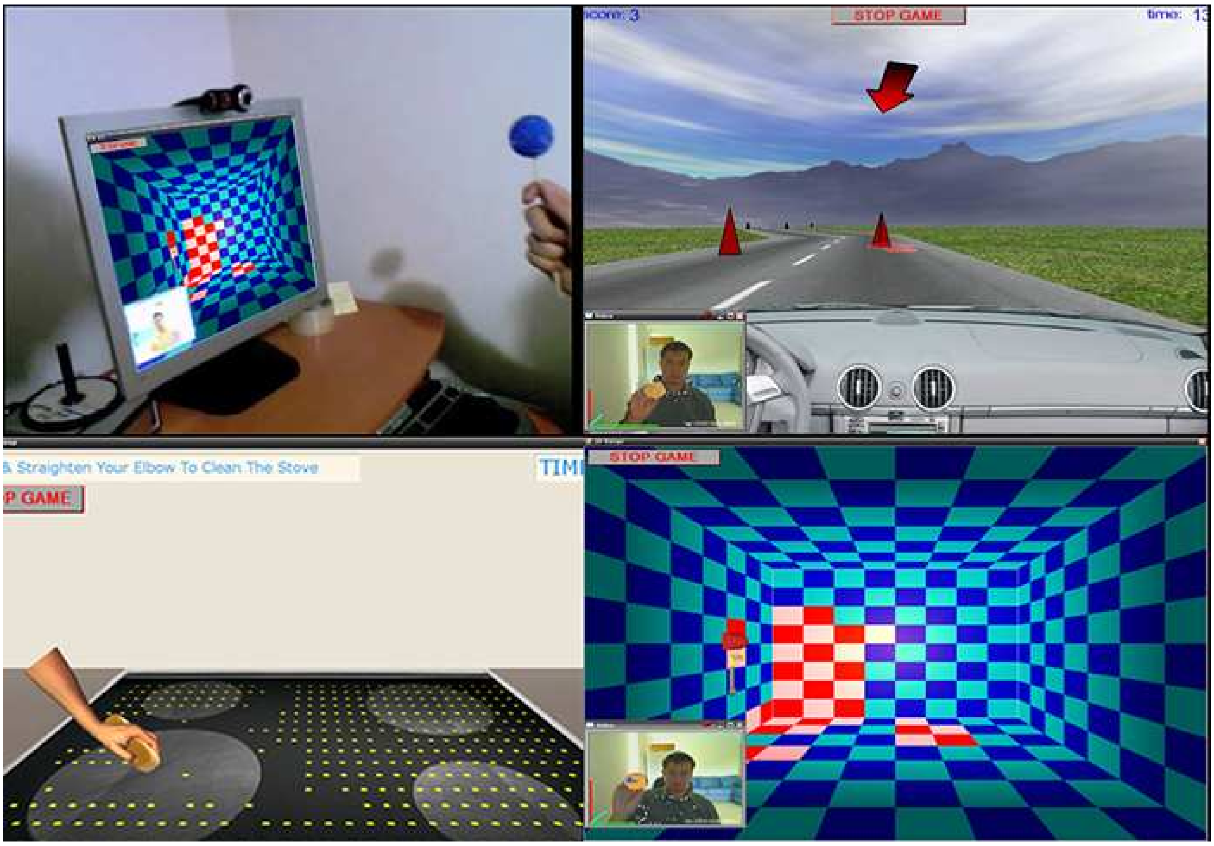

Fig. 1. Gesture Therapy. **Up,Left**: Computer with the Gesture Therapy software and the monocular 3-D tracker, the web–cam (over the monitor) and the colored ball are shown. The 3D monocular tracker allows the user to have fine movements. **Up,Right**: The car racing game being controlled with arm movements. **Down,Left**: The stove cleaning game, useful for straightening and bending of the arm. The 3-D tracker provides excellent depth estimation. **Down,Right**: In the 3-D room painting game, the 3-D monocular tracker shows robust (x, y) and (z) estimation allowing the user to paint specific squares on the room.

a kinematic model of the arm, to determine the angles in the elbow and shoulder. Tao and Hu [13] attach 3 color markers to the arm of the patient to track the arm using a stereo vision system. Tao et al. [14] combine an inertial sensor with visual tracking of the hand based on color information to follow the motion of the arm.

The use of accelerometers or inertial sensors in some of these systems difficult the natural movement of the patient arm. Other systems are difficult to use in a home environment as they require stereo vision systems or several markers attached to the patient arm. Finally, up to our knowledge, none these systems have been integrated into a working prototype, and they have not been tested in a clinical trail.

III. 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. Next we describe the simulated environment and then the tracking subsystem.

A. Simulated environment

The T-WREX [10] 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 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.

There are several simulation/games in the current prototype, including: Basket-ball, Car Racing, Wall Painting, Supermarket Shopping, and Cooking Eggs, among others. In Fig. 1 a few examples of different rehabilitation games are shown, and also a picture of the system and inserts depicting the results of the tracker.

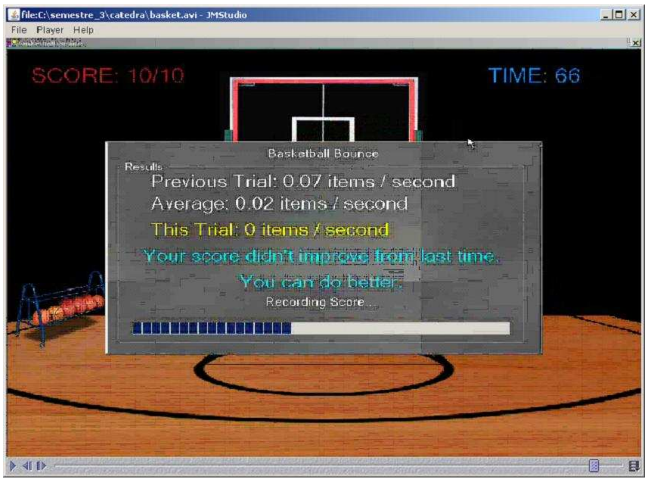

Fig. 2. Feedback given to the patient after playing the basket–ball game. The window shows the results (in terms of baskets per second) of this trial and contrast them with the previous trail; it then gives a *motivation message* to the patient.

Additionally, the system gives objective visual feedback of patient task performance as well as entertainment, 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 a patients awareness of his/her progress, as we found in our clinical results. Figure 2 shows an example of the feedback given to the patient in the *Basket-ball* game.

B. *Monocular tracker*

Based on a single low–cost camera and a computer, the hand of the user (via a 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 a Bayesian filter [4]. Initially, the object to be tracked is captured (in our experiments a blue ball) and a color histogram is obtained from the object region in the image. The histogram of each frame is compared to the training histogram, and using clustering the region of highest probability in the current frame is obtained. If the target's certainty level is above a threshold, then its position in 2-D, (x, y), is recorded. The target's size 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.

A general block diagram of the tracking system is depicted in Fig. 3.

The tracking subsystem was tested in the laboratory under different illumination conditions [7]. It was also compared to a stereo vision tracker to validate the estimates of the 3-D coordinates. The results show a robust performance under different illumination conditions with a small acceptable error in the depth estimate.

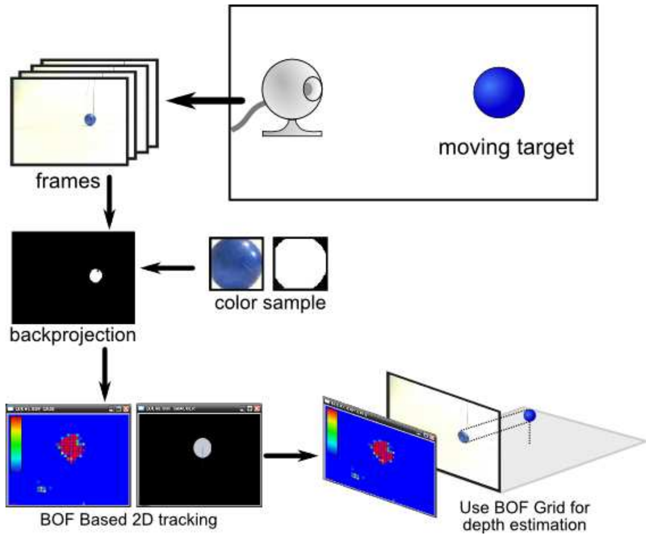

Fig. 3. General block diagram of the of the 3-D monocular tracker. The images are 2-D projections of the object onto the camera sensor. Then, using color histogram backprojection and a Bayesian filter, 2-D tracking is achieved. The occupancy grid of the 2-D tracker is used to obtain an approximation of the size of the object in the grid's cell units. By knowing the real size of the object and the discretization of the grid, an estimation of the depth is possible.

IV. 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. The Rehabilitation Unit at INNN has a staff of experienced physical therapists and it is specialized in treating stroke patients. It is a longitudinal and comparative study with patients that have suffered a stroke, ischemic or hemorrhagic. The inclusion criteria were that the patients were adults and accepted to participate in the study; patients who had other illness were excluded from the study. The remaining 15 patients were divided randomly into two groups; a control group with 8 patients, and an study group with 7 patients. There were in total 8 female patients and 7 males; the age range is from 43 to 68 years old with an average of 52.37 for the control group, and from 30 to 72 years old with an average of 50.8 for the study group. Both groups received treatment for 20 sessions, 45 minutes each. The control group received conventional occupational therapy, while the study group used the Gesture Therapy system guided by a therapist. The therapist determines which games to use for each patient according to goals established in a previous clinical evaluation.

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 basket–ball.
- Cleaning the windows.
- Cleaning the stove.
- Painting the walls.
- Preparing a hot dog.
- Driving in the highway.

The therapist selected different games according to each patient and their evolution during the treatment; and instructed the patients on how to use the games in the first sessions.

The GT system was installed in a room with artificial lighting at the rehabilitation unit at INNN; it was operated by the therapist after a brief tutorial by the designers. In general it worked properly, there were some minor technical problems that were solved by the technical staff.

B. Results

The impact of the therapy for both groups was evaluated using 3 different scales: (i) the Fugl–Meyer (FM) scale [3], (ii) the Motricity Index [11], and an Intrinsic Motivation Survey [2]. 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 just at the end of this phase of the clinical study.

Both groups present a significant improvement (according to the Wilcoxon statistical test with $p < 0.5$) after the 20 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 56.6% to 68.2% in the control group, and from 31.5% to 45.1% in the study group. There is also a notable improvement in FM, from 31.3 points to 45.1 points in the study group, and from 23.5 to 37.5 in the control group. When we compared both groups in terms of both, the Motricity Index and the Fugl–Meyer scale, their is no significant difference.

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 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.

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

C. Discussion

Based on this first clinical study, we conclude that the clinical impact of Gesture Therapy is similar to conventional occupational in therapy in terms of the motor and functional recovery of the affected upper extremity. Additionally, 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. These are promising results, as we expect that GT can be used at home without the need of an always present therapist. After we finish the clinical trail in the hospital, we plan to conduct a study with the patients using the system at home.

V. 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 always present a 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.

A. Evaluation and feedback

We have developed a technique to evaluate how well did a patient do certain movements, to quantify her progress and provide quantitative feedback [8].

To qualify arm gestures we propose the use of hidden Markov models (HMMs) [9]. A HMM is trained based on the reference or *correct* gesture. Then, samples of the gesture that we want to qualify are used to train a second HMM. Both HMMs are compared, and a measure of their similarity is used to qualify the gesture. We tried different metrics to compare HMMs, in particular the Levinson, Kullback–Leibler and Porikli metrics.

As visual input we consider the motion of the arm of a person. Three markers are attached to the arm, one in the wrist, a second in the elbow and a third in the shoulder. A stereo vision system is used to track the 3 markers in 3–D, from which a wire model is built to represent the motion of the arm. From this model, the motion in polar coordinates is obtained, and used as observations for training the HMMs.

We evaluated experimentally the gesture qualification system with different patients under rehabilitation after stroke. We consider three typical arm movements used in therapy: flexion, circular and abduction; and trained HMMs for healthy persons, and for several patients at different stages in the rehabilitation process. The results were compared with the scales that are used in therapy, in particular the Motricity

Index and the Fugl–Meyer scale. From the analysis of several experiments, the Porikli metric was the best to qualify the three gestures, in particular in terms of the motricity index.

B. Adaptation

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. [5]. The POMDP estimates the patient's state in terms of fatigue and stretch by measuring three observables: (i) the time it takes to complete an exercise (a particular game), (ii) the score reported by the simulated environment, and (iii) the way the patient does the arm movements. Based on the state of the patient, and certain predefined utility function, we obtain a policy on how to adjust the level of difficulty in the simulated games by solving the POMDP. Then, this policy is used to do an automatic adjustment of the Gesture Therapy system, in particular we consider adjusting the 3-D space in which the patient does the exercises with the impaired arm. This space is set in a calibration procedure whet the patient starts a session with Gesture Therapy, and using this technique it could then be adjusted dynamically according to the progress of each patient.

In the future we plan to integrate both components, the feedback mechanism and the automatic adjustment, to the Gesture Therapy system.

We will also add a scale for depression and wrist worn actigraphy to capture objective measures, patients compliance, and reduce reliance on anecdotal reports of behavior profiles between clinic visits.

VI. Conclusions

We have developed Gesture Therapy, 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 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 phase of an ongoing clinical trail shows similar results in rehabilitation in terms of clinical scales for patients using Gesture Therapy to those receiving conventional therapy. Additionally, 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 eventual recovery. We are continuing the clinical trail with more patients and expect to report more conclusive results in the near future.

Acknowledgments

This work was supported in part by a grant from Salud–CONACYT C01-70074, and under a grant from the Department of Education NIDRR grant number H133E070013. However, those contents do not necessarily represent the policy of the Department of Education, and you should not assume endorsement by the Federal Government.

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