P1 - Poster Session

Preliminary Results from the Use of the SOFTROBOT Platform in Stroke Patients*

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Abstract. Stroke patients tend to suffer from mobility impairments, whether it is in upper or lower limbs this mobility and/or coordination loss translates directly into a decrease in independence and quality of life. Those patients if quickly inserted into neuro-rehabilitation programs, can regain some of the lost capacities they used to have thus improving their quality of life. This study aims at evaluating the effectiveness of haptic robotic aided therapies when applied to stroke patients. Though lacking a control group, the improvement in the mobility of the patients can be seen both, quantitatively and qualitatively.

1 Introduction

The use of robotic devices for rehabilitation purposes has proved to be an excellent tool that helps on administering physical therapy to patients that suffered neurological injuries and diseases. Several studies have proven that arm therapy has positive effects on the rehabilitation progress of stroke patients [1].

The goal of robotic therapy control algorithms is to drive robotic devices designed for rehabilitation exercise, so that the selected exercises to be performed by the participant provoke motor plasticity, and therefore improve motor recovery. Currently, however, there is not a solid scientific understanding of how this goal can best be achieved. Robotic therapy control algorithms have therefore been designed on an ad hoc basis, usually drawing on some concepts from the rehabilitation, neuroscience, and motor learning literature.

There are many examples of modern rehabilitation platforms [2] [3] [4] [5]. Most of them include rich multimodal interfaces enhanced with interactive

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virtual reality environments, high performance haptic robots, exoskeletons and more.

The use of robotic technologies in neuro-rehabilitation has been subject of great development in the last 20 years [6]. The use of robotics systems in this field[4] provides us with more intensive, controlled, task oriented and interactive therapies. It also provides us with new tools for measuring patients progress. Several studies [7][8] have been published in order to demonstrate the effectiveness of robotic assisted training in patients with traumatic brain injury. Almost every study published up to this date[9] shows that patients who receive electromecanic training (by means of robot assistance) commonly don't show better chances to improve their upper limb movement in most of the activities of daily living (ADL). Nevertheless they show significant growth in motor function. In a second and more recent revision [10] the conclusion drawn is that robotic therapies can help the recovery of motor function at the proximal end of the upper limb which can, in turn, become an improvement in motor control making it better than traditional therapy alone. Another conclusion drawn is that this improvement can be observed even in chronic patients.

In this work we will examine some preliminary results obtained by including robotic aided therapy in upper limb rehabilitation with the SOFTROBOT platform. The evaluation method includes the motor assessment and fugl-meyer scales along with a custom metric based on the game score.

2 Materials and Methods

2.1 Hardware and Software

Figure 2 shows a block diagram, that describes the whole SOFTROBOT platform. In summary, a haptic robot equipped with a JR3 force/torque sensor mounted at the end effector is used as the center hardware platform for the system. Several types of data flow through an IP network to exchange information from motion data, to physiological signals (optional) using a Biopac system, which let us, gather real time data at different sample rates. All the raw and processed information, is then stored in a relational database for analysis and research. Several physiological and dynamic data is registered and stored online as temporal series for online control and offline analysis.

SOFTROBOT (see Figure 1), was conceived to be an intrinsically secure robot, designed to be the way it is, mainly searching for transparent dynamics, back drivability and safety.

The mechanical structure proposed was that of a Gantry robot similar to the one proposed in [11] (see Figure3, mostly because of the following features they intrinsically posses :

- Quasi isotropic inertia tensor may be achieved due to similar mechanics on both axes.

Fig. 1 SOFTROBOT Platform

- Simpler design, makes IK(Inverse Kinematics) and DK(Direct Kinematics) straight forward to compute, therefore reducing computational costs.
- Forces due to gravity, are structurally compensated, so there is no need to include a gravity compensation model.

One of the first design requirements, was to keep robot dynamics low. This was meant to be achieved with a simplistic mechanical design. However, commercial parts available for the robot, were all designed for high rigid geared mechanisms, and so, rails static and dynamic frictions were considerable high on all of them.

As the main purpose of this design was the intrinsic security by means of the backdrivability of the actuator/gear couple, high performance DC maxon brushless motors augmented with a $4,3:1$ geared transmission were chosen in order to get a good weight/torque ratio. The effects of the low ratio gear boxes were quiet beneficial, since, backdrivability is not lost, the total output torque is significantly increased and it also managed to cancel some complex to manage nonlinearities like the cogging torque due to the permanent magnets on the brushless motor, as well as surface friction discontinuities due to dust or any other solid particles on the rails.

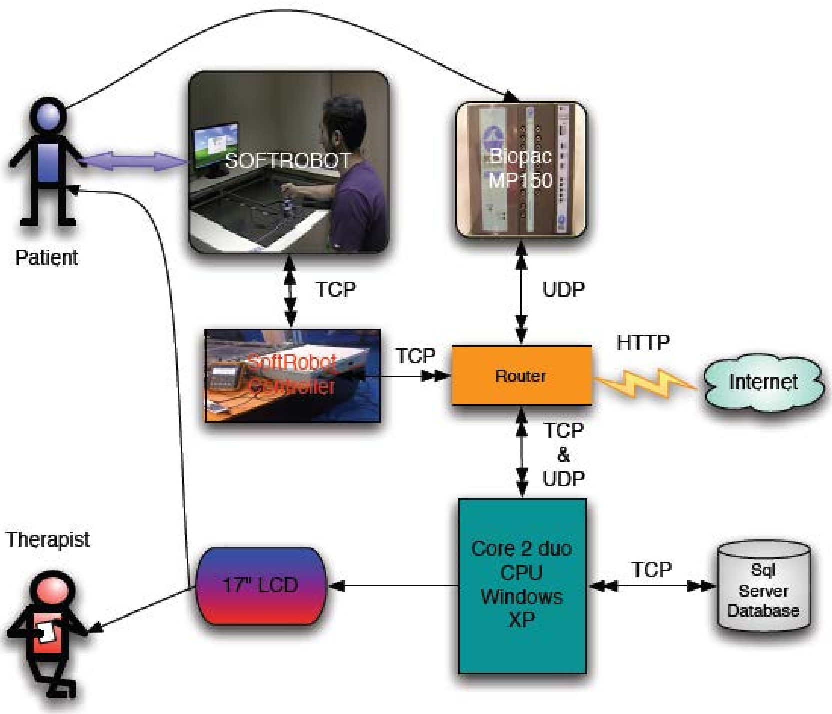

Fig. 2 SOFTROBOT architecture

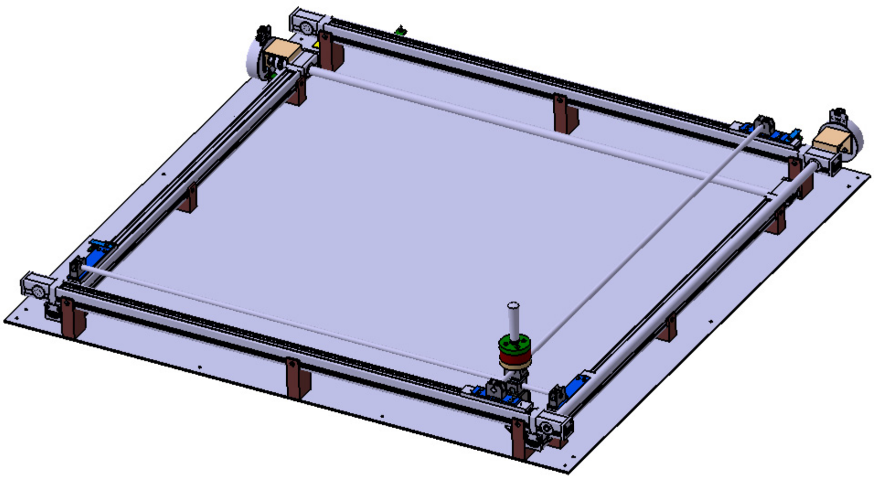

Fig. 3 SOFTROBOT platform design

2.1.1 Hardware Security Layer

SOTFROBOT has redundant security by means of hardware and software. There are 4 limit switches (see figure 3 black sensors over a blue plate on the extremities of each rail) that cuts motor driving currents when getting close to the mechanical hard stops on every rail. This helps not only to safety, but to prevent hardware degradation over time by possible impacts.

2.1.2 Software Security Layer

Along with the pure hardware security, we have implemented virtual viscoelastic walls close to the edges of the robot limits, in order to prevent impacts while maintaining compliancy.

2.2 Haptic Control

Haptic control strategies are most of the times, determined by the available type of hardware. Whenever you have backdrivable actuation or not, it will dictate if you can use either impedance or admittance control. For instance, if you have non backdrivable actuation open loop impedance control by itself is not realizable. Because SOFTROBOT's hardware is in principle backdrivable, it is possible to look after an impedance control strategy. However, due to the high friction rails with stick slip, coulomb and viscous effects, we used a solution based on merging a force feedback impedance control scheme with augmented with a feedforward model based control. The result can be seen on the block diagram in Figure4. This scheme features a plant model that allows us to deal with some of the undesirable dynamics that affects the transparency of the system.

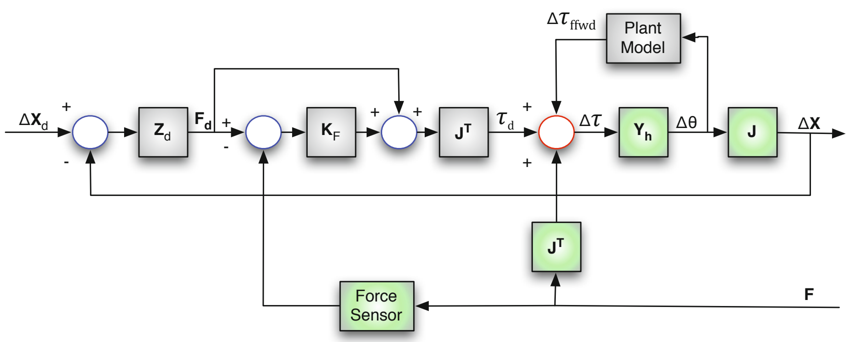

Fig. 4 SOFTROBOT controller block diagram

2.3 Operation Modes

The SOFTROBOT offers two operational modes. The first one is passive mode, in which therapist moves the robot end effector (with the human attached) in the way he/she wants the trajectory to be performed both in space and time. Then the therapist is prompted to enter an assistance level, which is a percentage of the total amount of power the robot is able to render, and finally the robot "re-play" for a given amount of time, the recorded trajectory and creates a viscoelastic force tunnel along the recorded path. The other operational mode is the active assistive mode. This mode offers a task oriented therapy type, augmented with a simple assisted as needed algorithm that modulates the amount of help given by the robot, based on the subjects performance.

A virtual computer mouse keeps wandering on a virtual desktop until the patient, represented by a virtual hand is able to catch it. Once the mouse is caught, the game score is increased by a certain amount, and the mouse flees from its position through virtual repulsion field with its center at the patients hand and so generating a new task in a pseudo-random way.

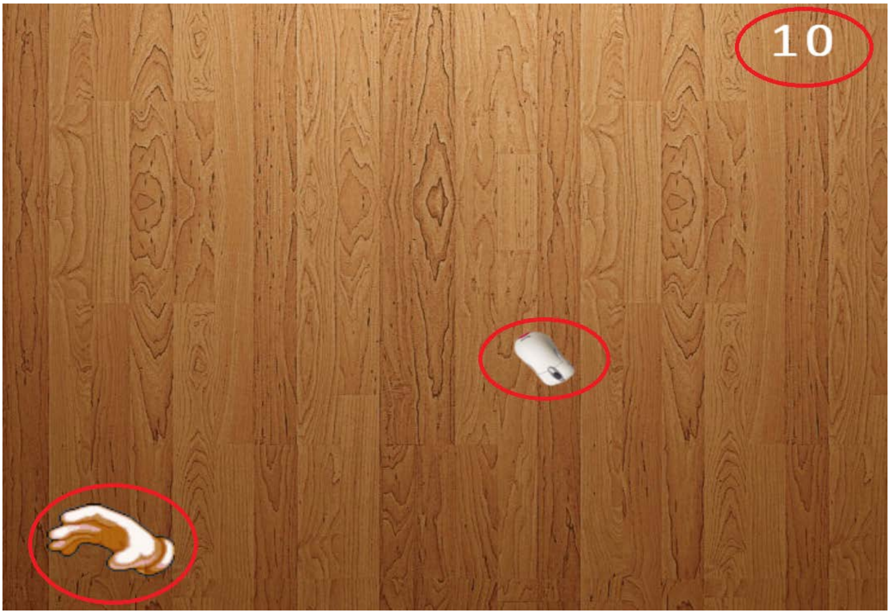

Fig. 5 Virtual reality game for the active assisted operational mode

2.4 Study Structure

We designed a longitudinal, pre-post, non controlled study in order to assess the effectiveness of a robotic system for the retraining of the upper limb in adult patients with traumatic brain injury of various etiologies.

2.4.1 The Study Group

8 Patients were selected among those with traumatic brain injury of the Hospital Beata Maria Ana de Jesus in Madrid selecting those patients that fulfilled the following criteria:

- Patients with aquired brain damage with upper limbs limitations.
- Elapsed time from the injury > one month
- Ashworth score < 3.
- 18 years old or older.
- Barthel score > 60.
- Middle scores in both; motor assessment scale and Fugl-Meyer.
- A decrease in articular mobility in shoulder and elbow.

Patients who had shoulder pain, botulinum toxin infusions, physical impossibility to use the system, cognitive alterations, etc. were rejected from the study.

2.4.2 Evaluation

Each patient included in the study should complete a treatment consisting of 10 sessions of 30 minutes for five consecutive days per week. Each treatment session was organized in a 6 minutes active assisted session, followed by a 2 minutes resting period upon completing the 30 minutes of total practice. It was considered necessary to carry out a prior assessment session to define the most suitable system configuration for each patient (workspace, a proper ergonomic posture, etc).

3 Results

The primary results of the effectiveness of the study show how all the patients treated by intensive therapy assisted by robot within the program of rehabilitation of the hemiparetic upper limb, acheived a significant increment in the game scores obtained along the training sessions as it can be seen in Table 1 and Figure 6 respectively. Results also shows evidence on motor learning with a greater integration of the upper limb in the subject's own corporal schema resulting in higher scores on scales that measure the overall functional capacity and specifically in the wrist and hand.

Table 1 Game Score

PATIENT	First Session	Last Session	Mean	STD
1	13515	31306	21636	8830
2	18318	34881	27849	5016
3	11481	29403	18053	5346
4	5340	11621	7966	1326
5	25633	40278	36366	4464
6	13223	16649	13762	2760
7	6919	8225	8131	847
8	9980	13872	13028	2697

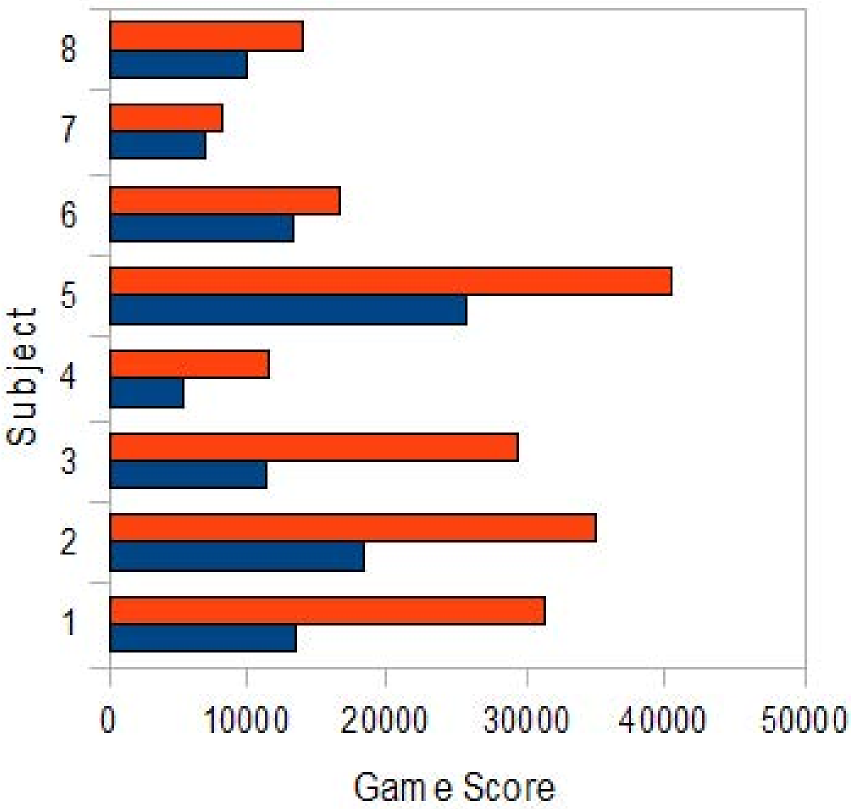

Fig. 6 Global game scores for each participant. First session(Blue) and Last session(Orange).

Table 2 Motor Assessment Scale

Subject	Arm Pre	Arm Post	Hand Pre	Hand Post	Fine Pre	Fine Post
1	5	6	5	5	4	5
2	5	6	5	6	5	5
3	5	6	4	5	2	3
4	6	6	6	6	6	6
5	6	6	6	6	5	5
6	5	6	4	6	4	5
7	6	6	5	6	4	5
8	5	6	5	5	2	4

Table 3 Fugl-Meyer Global Score

Subject	Wrist-Pre	Wrist-Post	Hand-Pre	Hand-Post
1	5	9	11	14
2	9	10	14	14
3	9	9	12	12
4	10	10	10	14
5	10	10	13	14
6	10	10	12	14
7	10	10	11	14
8	10	10	6	8

The Motor Assessment Scale (Table 2) showed increase in scores for the function of the upper member, movement of the hand and its fine movements.

It was shown in the scores obtained in the Fugl-Meyer Scale for the items of hand and wrist (Table 3) that scores increased "post intervention". This fact is very significant when seen at the same time as the results of the Motor Assessment Scale for mobility of hand and wrist, since movements primarily programmed in the development of the robotic system software components considered only the shoulder and elbow joints, and to a lesser degree the wrist and hand, the functional improvement of the hand is comparable to the therapeutic benefits found at proximal level in shoulder and elbow.

Secondary therapeutic benefits to the development of robot-assisted therapy included a subjective appreciation of a greater integration of the upper hemiparetic limb patients in their body's outline as well as greater automatic functional use of the upper limb in the development of the ADL.

During the development of the session, it was shown that robot-assisted therapy and the software used, constitute a powerful feedback for patients who are motivated in achieving a higher score between sessions and positively appreciated the changes that take place during the scheduled training time. It is also important to note that patients were eager to continue using the system due to their own perceived improvement.

4 Conclusions

We have observed significant improvement in all of the patients exposed to the intensive robotic rehabilitation program exposed before. The scores on the scales improved sensibly and the subjective appreciation of the patients was positive as well. The subjects perceived, in a subjective way, an increase in the functional ability of the hemiparetic upper limb in the development of the AVD that correlates positively with objective improvement in the scales of functional assessment for the items of wrist and hand.

Although the wrist and hand movements were somehow restricted, improvements on the functional ability and motor control also occurs at those two distal components. The results of this study were positive regardless of the stage of evolution in which the patient was, by varying themselves from the subacute phase to the chronic phase. The absence of a control group and the small size of the population, adds the necesity for a more developed clinical trial that will minimize the methodological biases existing in the present preliminary study.

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