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Wrist-RoboHab: A Robot for Treatment and Evaluation of Brain Injury Patients

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Abstract—**This article, introduces a new haptic robot, wrist-RoboHab, for upper limb rehabilitation of post stroke, orthopedic and Parkinson patients., . The robot is designed for hand movement therapy and could be used for both treatment and evaluation purposes in three operational states; forearm supination/pronation, wrist flexion/extension and ulnar/radial deviation. At first the mechanical design and control system are described. Then the results of a case study are demonstrated. Clinical results, showed an improvement in Fugle-Meyer, AROM, power and the biomechanical assessment of the spasticity in a chronic patient. Furthermore, it was approved that the robot can have a good interaction with both, patient and therapist.**

Keywords-component; haptic; rehabilitation robotics; Stroke; upper limb

I. Introduction

Thirty percents of patients that survive from stroke suffer from disability in the forms of partial or complete motor limitation of upper and lower limbs [1]. Traditional physical therapy exercises, based on passive manipulation of the paretic limb, require manual interactions with the therapists, which is extremely tiring, due to the high resistance of spastic muscles. The robotic rehabilitation devices, introduced in recent years, can undertake the difficult physical therapy tasks and provide improved treatment procedures, using new sensory-motor rehabilitation techniques, for post stroke patients. It has been reported that robotic rehabilitation shortens the recovery time, reduces the ennui of patient and therapist and prevent soft tissue and joint injuries [2].

A variety of robotic rehabilitation systems have been introduced in the literature from simple 2 DoFs unilateral robotic manipulators [3] to more complicated 6 DoFs robots that can apply mirrored bilateral exercise in 3D space [4, 5]. We describe here a simple and effective upper limb robot-mediated rehabilitation device for providing bilateral 1 DoF therapeutic practices. The overall design of this system is based on Bi-Manu-Track [6], however, the operational states have been increased and new working modes have been implemented to extend the applications of the system in treatment and evaluation of the post stroke, orthopedic and Parkinson patients.

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II. Method

A. Mechanical Desgin

Wirst-RoboHab is designed for passive or active unilateral or bilateral therapeutic exercises of the upper limb in three operational states: pronation / supination of the forearm, and flexion/extension and ulnar/radial deviation of the wrist [7]. The system includes two actuating-sensory units, for patient's paretic and unaffected hands, mounted on a table. Two linear guides allow the units to move along, so that the distance between the patient's hands can be easily adjusted(Fig. 1).

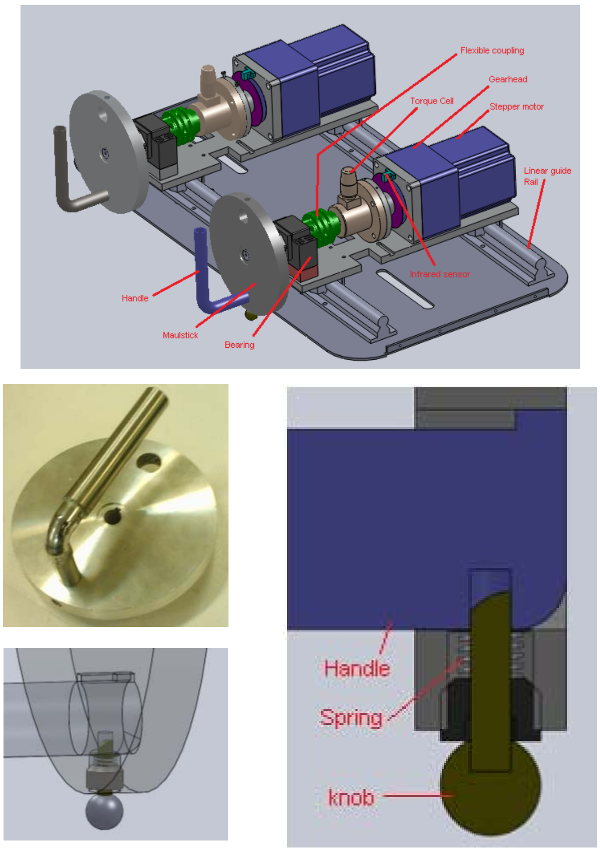

Figure 1. Schematic design of the wirst-RoboHab (top) with a maulstick for handle installation (middle left), and a spring mechanism for fast and easy handle locking/release (buttom right).

Each unit includes a stepper gear motor, which can provide up to 14Nm torques at 300 rpm continuously. The torque sensors attached to these motors can sense the applied torques in the range of -20 to 20 Nm. Flexible couplings have been also implemented to protect the sensors from radial and axial loads.

In order to enable changing between operational states, the table is capable of rotating 90 degrees to change the rotation axis. A maulstick with two holes, connected to each shaft after the bearing, allows for installation of a handle associated with each of the operational states (Fig. 1). A spring mechanism facilitates the handles installation and removal, so that switching between the states can be performed easily and fast. Once the operator locates the handle inside the hole, the spring drives a locking pin to make it fixed. On the other hand, in order to release the handle, it is sufficient to pull out a knob.

To guarantee the patient's safety during exercises, we have used a micro switch on either actuating-sensory units of the system that disconnects the power at the end range. In addition, there are two mechanical stops attached to the end ranges, and an emergency stop button which uses a push-to-stop, twist-to-release mechanism to provide emergency stop actuation.

B. Data collection and control

The analog data of each torque sensor is amplified and filtered then converted to digital using a microcontroller. A combined Fuzzy - digital PID controller, is used to control the driving motors. Details of the Fuzzy controller design have been described elsewhere [8]. The parameters of the PID controller were tuned using a dynamic try and error method via three potentiometers, connected to the microcontroller.

The system can function in seven working modes for patient treatment and three working modes for patient evaluation. A graphical user interface is available for switching between working modes, as well as for adjusting the parameters and providing visual feedback for both patient and therapist. Furthermore, the robot can be connected to a computer via a USB port to facilitate the user communication and data transfer.

The most commonly used working mode of the robot for treatment of spastic patients is the passive mode. In this mode, the robot moves the patient's paretic and non-paretic hands within a range of motion determined by the therapist. Considering the fact that the speed of motion is one of the most important parameters in passive manipulation of spastic patients, we have designed a fuzzy controller for this mode [8]. This controller adjusts the exercise speed based on the level of spasticity, determined by the therapist as Brunnstrom's score [10], and also the resistance sensed by the torque sensors dynamically during motion. This sophisticated controlling approach allows the exercise speed to change smoothly and safely, within the range of motion, similar to what one expects from an experienced therapist.

Semi-active, is a haptic treatment mode for spastic patients in which the patient moves his unaffected hand (master) to drive the robot (slave) that moves the paretic extremity in mirrored direction. The torque at the slave side is monitored and applied to the master side as a force feedback to provide a real-time dynamic sensation of the resistance at the paretic hand and prevent excessive torques. This is an essential consideration since the patient might move his unaffected hand too fast causing injury to the paretic side. Moreover, the system is capable of limiting the moving speed when a high resistance is monitored at the paretic side. The sudden increase of the spasticity in paretic hand due to high speeds can cause a sudden change in the speed disrupting the smoothness of the exercise and making it stepwise.

The resistive mode for patient treatment is almost the same as the active mode as the unaffected hand of the flaccid patient at the master side controls the motion of the paretic hand at the slave slide. However, here a prescribed torque, set by the therapist, is also applied to the master side to limit the exercise speed. In active-assisted mode, the patient makes effort to move the paretic hand against an adjustable resistance and is assisted, in some degree, by the unaffected hand. The active-constrained mode is another working mode of the robot for treatment of post stroke patients. In this mode, the patient makes effort to move the healthy hand while the corresponding handle is fixed, and the torque and the angular motion at the paretic hand, due to the brain irradiation effect, is recorded.

Figure 2. Wrist-RoboHab in (top) supination/sronation and flexion/extension operational states.

We have also implemented an orthopedic rehabilitation mode in the robot for treatment of patients after colles fracture or hand surgery. In this mode, the robot moves the patients hand passively until the resistance of the hand rises up to a set point determined by the therapist. The system records this position and stops there for a period, and then backs to the mid position and starts the movement again. In the next run, the system continues its movement to reach a position five degrees further than the previous endpoint regardless of the resistance. This procedure is repeated several times until the range of motion prescribed by the therapist is achieved.

Finally, a Parkinson rehabilitation mode has been implemented in the robot for helping the patients suffering from Parkinson disease. In this mode, the handles of the system can move freely with low impedance. The patient traces a moving circle in the virtual space and is encouraged by an auditory feedback if he could move his hands simultaneously and smoothly.

One of the most important features of wrist-RoboHab is its capability to work in the evaluation mode and provide information of the patient's level of injury. There are of course some established measures for this purpose used conventionally by clinicians. A typical example is Ashworth scales used widely for assessing the spasticity level in adult patients with brain injury [11]. However, while such clinical scales offer only subjective information, the wrist-RoboHab is capable of measuring the spasticity of elbow and wrist flexors at a constant velocity and provides an objective measure of spasticity. Such quantified information, provide a valuable biomechanical assessment of the level of spasticity defined as the resistance to passive movement versus joint angle. The system is also capable of measuring the patient's hand active range of motion. In this mode, patient moves the handle with low impedance and the end points, are recorded as ROM. Finally, in the evaluation mode designed for determining the passive range of motion, the handles are free to move and the therapist drives the patient's hand while he grips the handle. This motion continues until the therapist perceives the end feel and press a button to save the data.

C. Experiments

A case study was conducted on a female spastic hemiplegia patient, aged 62 years, 48 months after ischemic stroke. The robotic rehabilitation protocol was designed to include 20 sessions of treatments in 6 days a week, 75min per day. Each session contained two main stages. First, the patient experienced NDT treatment [12] for 30 min, and then was subjected to robotic rehabilitation treatment. This was performed in two operational states, i.e., supination/pronation and flexion/extension, and five phases: (1) 30 cycles of passive mode, (2) 10 cycles of semi-active mode, (3) 5 cycles of passive mode, (4) 5 cycles of active-assisted mode, and finally (5) 5 cycles of passive mode.

Clinical evaluation tests were conducted on the patient at 1st, 10th and 20th sessions, including the Fugle-Meyer (FM, maximum score = 66) [13], modified Ashworth scale [14, 15], AROM [16], power [16], and box and block [13] as shown in figure 3. Biomechanical assessment of spasticity was also performed in the aforementioned sessions to determine the change of the patient's spasticity objectively.

III. RESULTS

The results of the patient's evaluation tests are shown in Table 1. The active range of motion of our patient improved in forearm, elbow and metacarpophalangeal by about 10, 5 and 50 degrees respectively. The increase in power, box and block test, and Fugle-Meyer score was also considerable.

The data of figure 4 illustrates the results of measuring the patient's spasticity objectively. The results indicate that, at the 1st evaluation, patient's spasticity caused a resistance about 5.8

Figure 3. The patient during measurment of the metacarpophalangeal range of motion (left). and conduction the box and block test (right).

TABLE I. RESULTS OF EVALUATIONS

		Pre-test	*Discharge*	*Pre-test to discharge change*	*Follow up*	*Discharge to follow up change*
AROM	Forearm (Sup/Pro)	75	85	10	85	0
	Wrist (Flex./Ext.)	70	65	-5	65	0
	Elbow	110	115	5	115	0
	Metacarpophalangeal	20	60	40	70	10
Power		6	6	0	10.5	4.5
Box and block		14	20	6	26	6
Fugl-Meyer		49	50	1	51	1
MMAS-Elbow		1	1	0	1	0
MMAS-Wrist		1	0	-1	1	0

Nm, that was decreased to 4 Nm and 3.6 Nm at the 2nd 3rd evaluations, respectively.

IV. DISCUSSION AND CONCLUSIONS

In this study, a simple and effective robotic rehabilitation device for treatment and evaluation of post stroke patients was introduced. Our clinical study demonstrated that the robot can effectively interact with both therapist and patient. The results of the clinical evaluation indicated significant improvements in different parameters, e.g., ROM, FM score and power. This was in spite of the fact that a long time, over 48 months, was passed from the time of the stoke and such patients are usually considered to show very slow rates of improvement.

The results of the biomechanical assessment of the spasticity using wrist-RoboHab indicate the efficacy of the robotic passive exercises to improve the spasticity of our patient's paretic hand. However, they should be performed cautiously since moving the spastic hand with an inappropriate speed, by an inexperience therapist, might lead to bone fracture, tendon rupture and pain. The fuzzy controller, employed in our robot for adjusting the exercise speed ensures a safe and smooth passive exercise based on the level of spasticity, and the resistance sensed by the system dynamically. We also believe that the improvement of metacarpophalgeal ROM and power, seen in our patient, are due to the robot exercises and the active role of the patient in moving the handles of the robot since the patient had to grip the handles.

An important feature of our robot is the capability of performing objective evaluation based on the accepted definition of spasticity as a velocity-dependent phenomenon. In this way, the examiner can use the robot to apply a range of speeds to measure the spasticity and view the data online on a torque-angle graph. This obviously eliminates the human errors due to subjective judgment with clinical scales, and provides more reliable and accurate estimations of the level of spasticity. Moreover, the quantitative measurement of spasticity allows evaluating the efficacy of treatments. As seen in Fig. 4, the robot demonstrated small, considerable reduction in spasticity throughout the treatment sessions. The qualitative clinical scales are unable to measure such small changes in spasticity. However, their observation is of great significance for the patient, from a mental point of view, since he/she is encouraged to continue the treatment.

The multifunctional feature of our robot, provides the therapist the opportunity to use it for patients with various kinds of disability, and makes it cost-effective and affordable. More research on a large number of patients is required to evaluate the efficacy of the system in more detail.

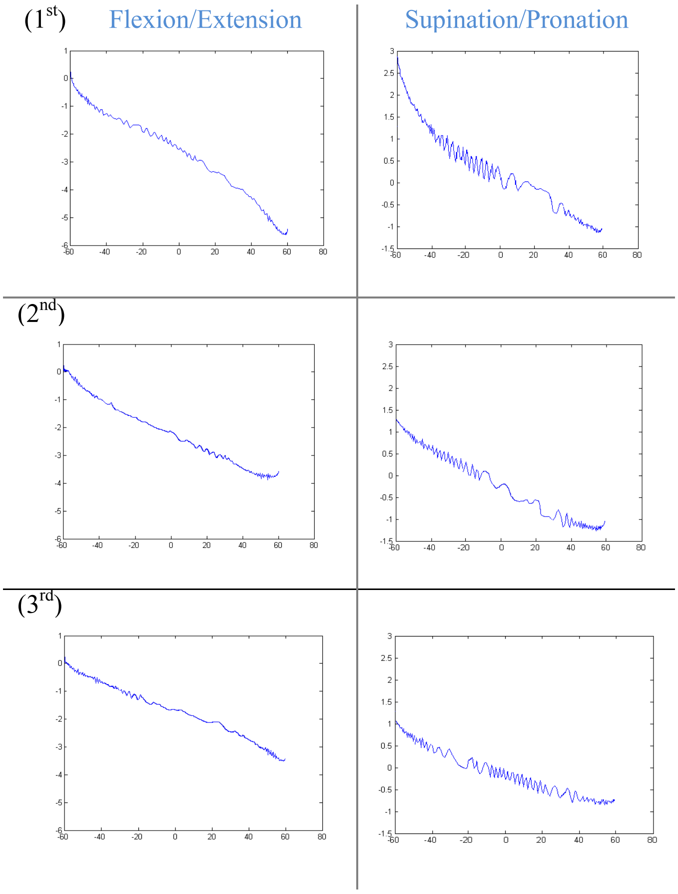

Figure 4. wrist-RoboHab evaluation results of the patient at the speed of 50 degrees/sec for flexion/extension (left) and supination/pronation (right) at 1st(top), 10th (middle), and 20th (buttom) sessions.The vertical axis is the resistance measured in Nm and the horizanal axis is the joint position from -60 up to 60 degrees.

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