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UPPER LIMB REHABILITATION THROUGH BICYCLE CONTROLLING

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Abstract. *Stroke survivors generally present upper or lower limbs sensory-motor deficits. As a consequence, activities recruiting two or more limbs – like walking, bimanual tasks or even riding a bicycle – are impaired. The great majority of rehabilitation therapies, from the conventional to the technology-assisted, focus on the most affected limb, neglecting cooperative activities with other limbs. According to recent studies, rehabilitation of the most affected limbs does not lead to the recovery of functions that require cooperation with the less affected, as previously hypothesized. On the other hand, recent studies point out that therapies which involve cooperation among limbs, like cycling a bicycle, may result in recover of others distinct activities – like walking and unilateral manipulation. This work presents the development of a robotic version of a bicycle handlebar. The device has two sensors in order to measure grip forces of the hands, the speed and amplitude of the movements when twisting the handlebar and a controlled electric motor as actuator responsible to apply torque resistance when the handlebar is moved. Pilot experiments with health volunteers, the authors, were conducted. As concept proof, this paper presents the device and discusses the preliminary results and next steps of the project.*

Keywords: *stroke rehabilitation, biomechanics, robotic rehabilitation, assessment, mechatronics.*

1. INTRODUCTION

Stroke is the second leading cause of death in the world. In general, the consequences for the survivors are severe. Around 40% of victims presents impairment of their limbs motor functions (Boyd, *et al.*, 2010). Conventional rehabilitation by one-on-one training with a therapist and technology-based therapy, as Robot-Assisted Therapy (RAT) and serious games, can reduce functional impairment and increase strength of the contralesional limb (Maciejasz, *et al.*, 2014).

However, in many cases these improvements do not reflect significant progresses in daily tasks that recruit coordination and cooperation of the most with the less affected limb. Regarding upper limbs, functional recover of the most affected can be observed on unimanual tasks. On the other hand, bimanual tasks, those recruiting both limbs working in parallel or in cooperation, are not improved, leading to a non-use learning. Results present in the literature suggest a limited transfer from unimanual to bimanual functions (Taub, *et al.*, 2006).

It is hypothesized that a key factor to improve RAT is the focus on bimanual activities (Sainburg, *et al.*, 2013). However, rehabilitation of bimanual tasks in a conventional or RAT training may be difficult due to challenges to simulate inner cooperation forces. The strategy considered in the context of this work is the interaction with instrumented devices designed as replica of daily life ones that can stimulate the patient to perform tasks with both upper limbs. This proposed immersive environment can be created by means of all sort of feedback systems, haptic, visual or sonorous (Maciejasz, *et al.*, 2014).

Based on this strategy, the Human Robotic Group, from Imperial College London, developed an interactive platform called SITAR (System for Independent Task-oriented Assessment and Rehabilitation), which is composed by a touch screen table with which the individual can interact guided by games. All interaction is realized with instrumented objects capable of functional measurement as interaction forces and movement (position, velocity and acceleration) (Roby-Brami, *et al.*, 2017).

The device presented in this paper was created in the SITAR context and was inspired by the activity of driving a bicycle. Firstly, because it is a complex task, involving the action of multiple sensor channels at the same time, coordination of muscles, either to keep the balance of the body or to give it power. Secondly, recent studies have suggested a close relation between cycling and the recovery of cognitive and neurological functions, either in patients with Parkinson's disease (Alberts, *et al.*, 2011) or in victims of stroke (Katz-Leurer, *et al.*, 2006; Ambrosini, *et al.*, 2011]. According to these studies, the positive outcomes in terms of a cognitive recovery, is only observed when forced exercise (FE) is performed. The FE is defined as the mode in which the rate of pedaling is mechanically increased in order to assist the individual to achieve and maintain a pace greater than his or her preferred one, however, the participant is always contributing actively to the exercise. One possible hypothesis to explain these results is that the FE cause a change in motor recovery strategy, from feedback to feedforward, maybe due to increase of intrinsic feedback received by CNS (Alberts, *et al.*, 2011).

This paper is organized as follows: section 2 presents the rehabilitation system proposed and a technical description of the current implementation; section 3 presents the pilot experiment protocol and its results; and on section 4 presents the conclusions, some discussions and next steps of the project.

2. REHABILITATION SYSTEM PROPOSAL

The complete proposed cycling rehabilitation system is composed by three major parts, a pedal, a handlebar and a display for serious game (Figure 1).

Figure 1. The complete proposed device

In order to simulate the real environment of cycling, the pedaling and the driving actions are combined thru a game (feedback unit), which can change the movement resistance either in the pedal or the handlebar. Both units are intended to be equipped with sensors from which would be possible to assess forces and movements of the patient. Load cells will measure the prehension force in the handle and other torsional forces applied to the handlebar, and an encoder will measure the handlebar and pedal angle position and their spin velocity or acceleration. According to what is stated in the literature and described in the Introduction section, the pedaling action has to be forced in order to produce cognitive effects. It means that the pedal unit must be equipped with an actuator system in order to produce a cycling rate higher than the one that the individual is able to achieve by him or herself.

This paper presents the results only for a preliminary version of the handlebar unit. The complete system will be tested and presented in future publications.

3. FIRST PROTOTYPE

The proof of concept was developed by constructing a first prototype for the handlebar unit of the proposed device (Figure 2).

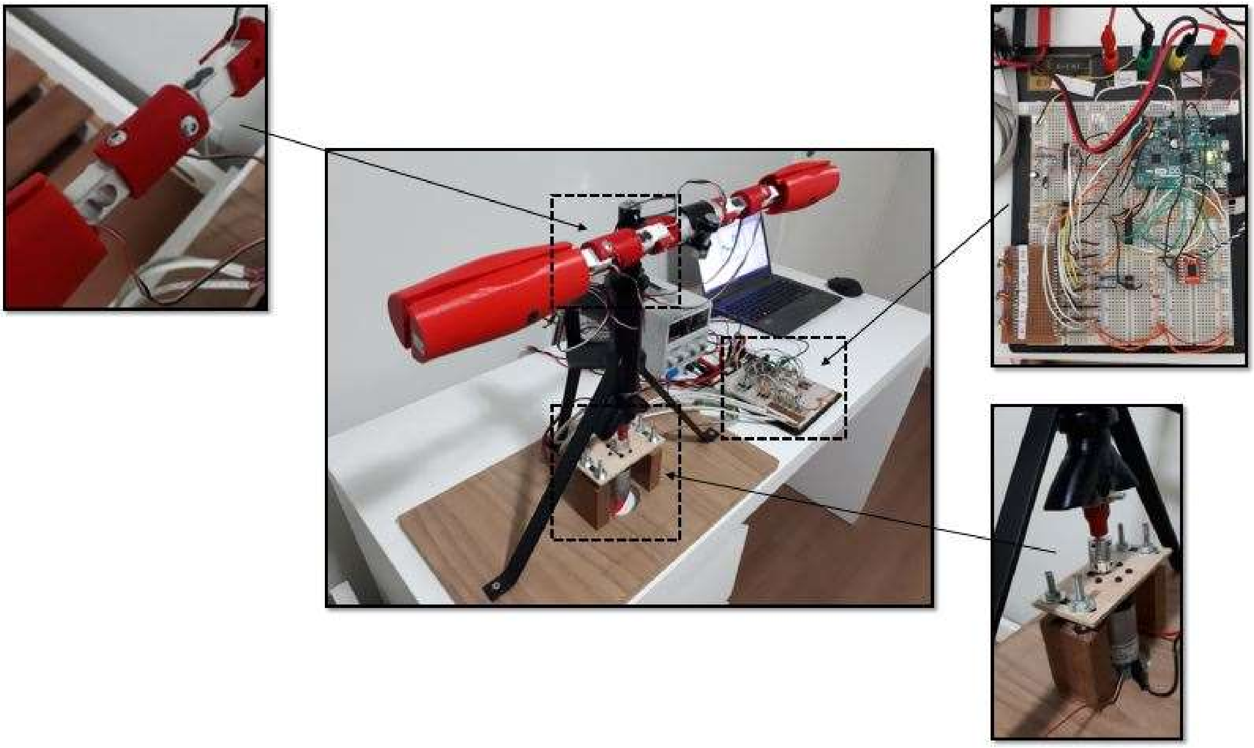

Figure 2. Details of the first prototype presented in this paper

As one can see in Figure 2, it was used very simple mechanical resources. The structure is made of wood together with adapted parts of an old bicycle: fork, head tube and its bearing box. Concerning the handlebar, mechanical parts were designed to interconnect each load cells, disposed side-by-side in a perpendicular orientation. These pieces were made with ABS and prototyped using a 3D printer. As Figure 2 shows, only the load cells placed inside the handles required a special plastic recover in order to make them ergonomically suitable.

Despite this being the first prototype, the electronics were designed considering the requirements of the final device. All the data acquisition and motor control is performed by an Arduino board, model M0 PRO. The program takes approximately 1.6 milliseconds (625 Hz) to get all the six measures with 13-bit of resolution each one, control the motor (PID control) and transfer data via USB to the PC.

The game used to produce the interface was developed in MATLAB® language. Figure 3 shows its main steps.

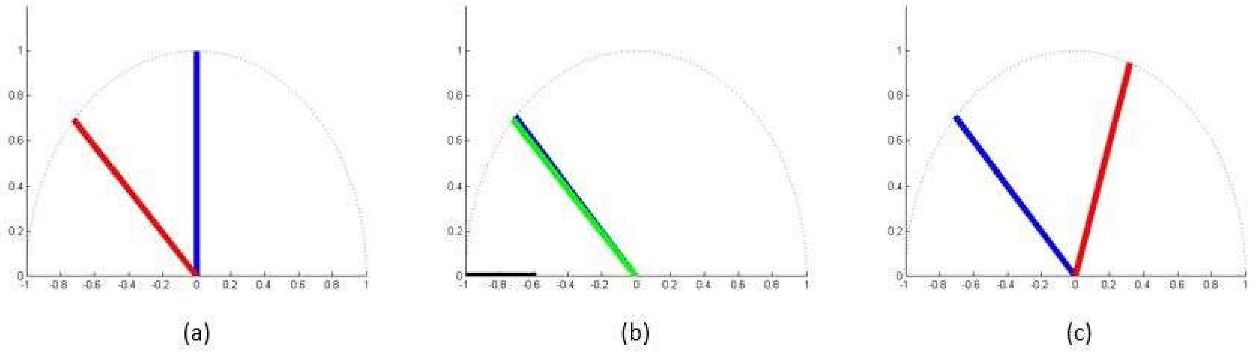

Figure 3. Main steps of the game that guides the participant during the experiment

First, a target pointer is created (Figure 3a, red line) according to a random angle between -90 and 90 degrees. The user is oriented to turn the handlebar changing the user pointer (Figure 3a, blue line). When the user pointer reaches the target (which becomes green, showing that the angle is valid), the game starts a timer (Figure 3b, the passing time is represented by the black bar on the bottom of the graphic). The user must hold the angular position during a certain period of time, that can be changed according to specific criteria. When the time limit is achieved the angular position of the target pointer changes automatically, starting a new round.

During all this task the system in able to produce a force field given to the user the sensation of resistance or assistance, depending on the aim of the task. This feature of the device helps the creation of different levels of complexity according to the desired motor task. During the experiment described in the next section, the produced force was acting to maintain the handlebar at the initial position (blue pointer in Figure 3a).

4. EXPERIMENT AND RESULTS

A pilot experiment was conducted with one volunteer in order to evaluate the feasibility of the system as a training device and its measurement capacity. The volunteer is the main author of the paper, with the following characteristics: male, 26 years at the time of the experiment, right handed and with no related neural nor motor disorder.

The experiment protocol was the following: both handles reached and held the handlebar approximately at the same time. As soon as they were touched, the handlebar was twisted counterclockwise for a little less than 90 degrees (due to a stablished ergonomic limit, according to the participant's posture during the experiment). Once achieved the final angular position, it was held for less than 1 second when the handlebar was twisted clockwise to the initial position again. After about 1 second, the inverse movement was performed. Top graphic of Figure 4 presents the angular handlebar position measured by the encoder. Due to its high resolution it is possible to observe the precise modulation of the angular position before the plateaus.

Figure 4 shows the main results for the experiment. The corresponding load cells, of both sides, are compared in the same graphic (blue and green lines). All the signals were filtered (post-processed) by a digital low-pass filter with 5Hz of cut frequency. From top to bottom, the second, third and fourth graphics, present the measured signals for the load cells, from the extremity to the center of the handlebar, respectively. All the three graphics indicate that the signals for corresponding cells are either similar (second and fourth graphics) or symmetric (third graphic).

From the second graphic, whose signals correspond to the load cells placed inside the handles measuring the prehension forces, it is possible to observe that the first contact with the handle is the highest moment of force application, while the lowest happen at the half of the experiment (probably because the center is the angular position in which the motor is not acting against the movement).

The signals showed in the third graphic are related to the recorded forces in the vertical direction. As one can see, those forces are different comparing each side, what may be interpreted as greater difficulty to sustain one arm in comparison to the other. This is a typical behavior among patients of stroke with motor disabilities.

Finally, the bottom graphic presents the forces measured in the direction of the twist, both signals clearly demonstrate the reaction forces in response to the spin movement with the motor acting in the reverse wise.

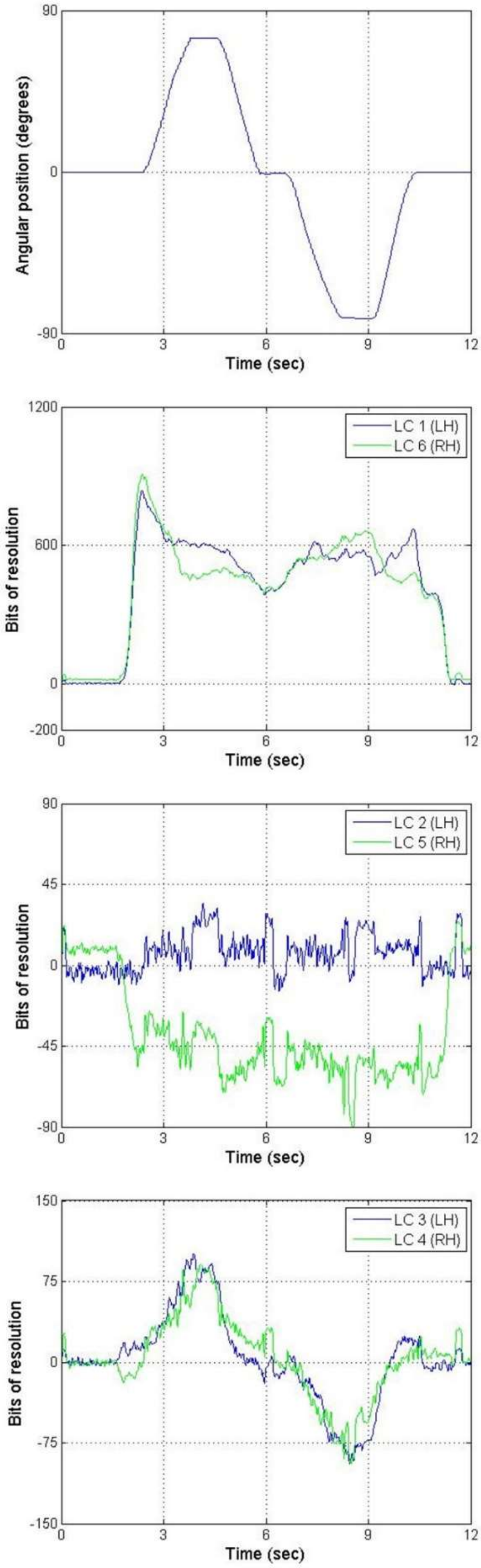

Figure 4. Experiments results. From the top to the bottom: the handlebar angular position, measure by the encoder, during the described protocol; signals for the left (blue) and right (green) load cells placed inside the handles (LC1 and LC6, respectively); signals for the left (blue) and right (green) most external load cells placed along the handlebar (LC2 and LC5, respectively). Both measure the vertical forces applied to the handlebar; signals for the left (blue) and right (green) central load cells placed along the handlebar (LC3 and LC4, respectively). Both measure the torsional forces applied to the handlebar.

In order to evaluate the measurement repeatability of the device, the protocol exercise was repeated 5 times. Figure 5 shows the results for the prehension force of the right hand. It is possible to observe that magnitude and force profile are similar in all the trials, mainly in the first 6 seconds of the exercise. Sound or visual instruction will be needed in future experiments in order to better synchronize data.

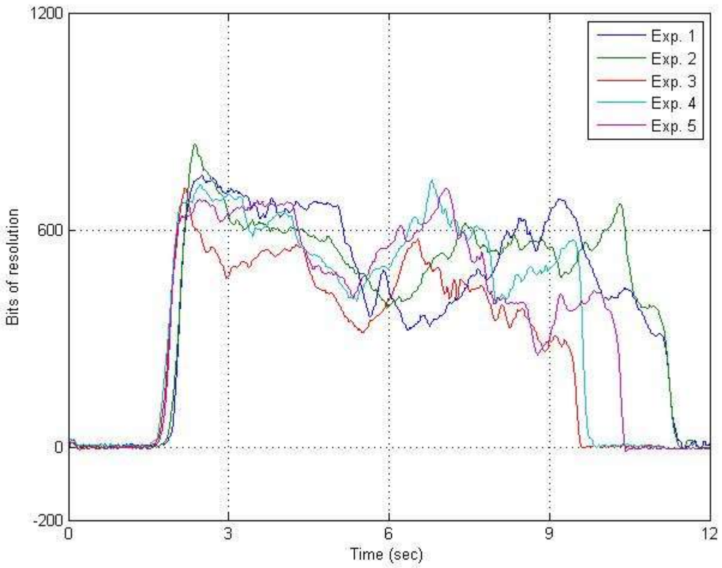

Figure 5. Right prehension force for 5 trials of the protocol exercise.

5. CONCLUSION, DISCUSSION AND FUTURE WORKS

A stroke, when not fatal, usually brings motor functional impairment as sequels for the survivors. In order to restore the movements, even partially, rehabilitation training is proposed. In general, the exercises are focused on the most affected limb, which can improve its amplitude of movements, strength and reduce spasticity. As a result, the ability to execute unimanual tasks is restored. However, recent surveys have revealed that bimanual tasks are not recovered as a consequence of the rehabilitation of the most affected limb.

In order to improve the rehabilitation of upper limbs, bimanual exercises with real instrumented objects are proposed. In this work it was presented an instrumented bicycle handlebar intended to be integrated to the SITAR system. The device technical details were presented and, as a summary, results indicate its capacity of measuring prehension forces of both hands, and vertical and horizontal forces of each side of the bar. The twist angle was also measured with a high resolution encoder attached to the motor shaft.

The acquisition system based on an ARDUINO M0 Pro proved to be efficient in the experiments. The total of 7 interaction values (6 forces and twisting angle) could be synchronously acquired as proved in the pilot experiment conducted with the main author. Signal properties as peak value, profile, as well as time correlation among forces and movement is important for proper understanding of bimanual skills in health subjects and for neural rehabilitation, and, as a consequence, it may conduct to a better understanding of the neural mechanism of bimanual function correlating brain damage to function characteristic obtained by signal evaluation.

In the paper it was also presented a user interface composed by a simplified serious game implemented in MATLAB. The game presents to the user the desired twisting angle for the handle bar as well as the current position. In a qualitative evaluation the interface was considered intuitive. Nevertheless, it may be improved in the next steps of the project with the inclusion of score, time and any other data that may be further relevant.

Concerning the actuation system, an experimental model of the motor was also obtained and results with a simple PID control was presented. The model is close to the real device and, therefore, it is mandatory for impedance control implementation in the next steps of the project. The final system will have an impedance controller as actuation system and its parameters, inertia, stiffness and damping changed from low to high impedance according to the level of difficult of the exercise, that can depend on the impairment of the patient.

Future works may also include the design and implementation of an instrumented and actuated pedaling device, thus the user will have to accomplish fully movements of riding a bicycle and implementation of a motion tracking system based on Kinect (Pedro, *et al.*, 2012,). It is hypothesized that the combination of movement of the four limbs may improve rehabilitation therapy. As a secondary benefit, the device can improve the patient health in general.

6. ACKNOWLEDGEMENTS

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8. RESPONSIBILITY NOTICE