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INSTRUMENTED MODULE FOR INVESTIGATION OF CONTACT FORCES FOR USE IN REHABILITATION AND ASSESSMENT OF BIMANUAL FUNCTIONALITIES

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Abstract. *The project aim is the development of a mechatronic module for rehabilitation training and assessment of contact and prehension forces through force sensors in bimanual tasks. Such a module would be used by people with motor deficits, victims of sequelae caused by cerebrovascular diseases such as stroke. The instrument is intended to interact with virtual daily activities simulated by games as it is part of the System for Independent Task-oriented Assessment and Rehabilitation, the SITAR system, with the purpose to restore upper-limb functions. Therefore, the working areas encompassed were the mechanics, electronics, computing and control of the device, focusing mainly on the first due to the basic structure of the object. Using a CAD software and 3D printing, it was conceived a prototype able to perform bimanual tasks and collect data from it. The device fulfilled the initial requirement of measuring the forces of interest and also presented satisfactory results since it was possible to observe a pattern along the exercise proposed for the pilot experiment performed by the authors. For statistical analysis of the forces profiles, a larger application of the experiment with patients and healthy volunteers will be carried out soon.*

Keywords: *stroke rehabilitation, technology-assisted therapy, bimanual assessment, mechatronics.*

1. INTRODUCTION

According to the World Health Organization, in the last 15 years, the leading causes of natural death in the world include cardiovascular e cerebrovascular diseases. In their most recent survey, only in 2015, more than 15 million people have become fatal victims of stroke, an ischemic heart disease, as shown in Fig. 1 (The World Health Organization, 2017).

As a summary, a stroke occurs due to insufficient blood flow in a particular area of the brain and can be divided into two categories: ischemic, which there is a blood blockage; or hemorrhagic, which there is an external blood flow to the vessels. Their main causes may vary among aneurysm, arterial hypertension, cardiopathy and thromboembolism. In Brazil, such a disease is very prevalent, which takes a life every 5 minutes (Portal Brasil, 2014) and leaves serious consequences in almost all survivors, such as speech disorder, partial loss of limb movement or even lateral or total body paralysis.

Based on data from the Ministry of Health in Brazil, considering the aging process of the population over the last decades and the increase in life expectancy, the proportion of stroke incidence tends to increase, mainly due to the increase in population morbidity. In spite of the alarming data, the mortality has declined considerably. In 10 years there was a 32% reduction in the number of deaths due to stroke (Portal Brasil, 2014), mainly because of the advances of drugs and the expansion of public health care. Despite the positive side of these numbers, surviving victims have several sequelae, creating a major social and economic impact as they lose essential skills to perform daily tasks, revealing a greater number of patients subjected to rehabilitation needs.

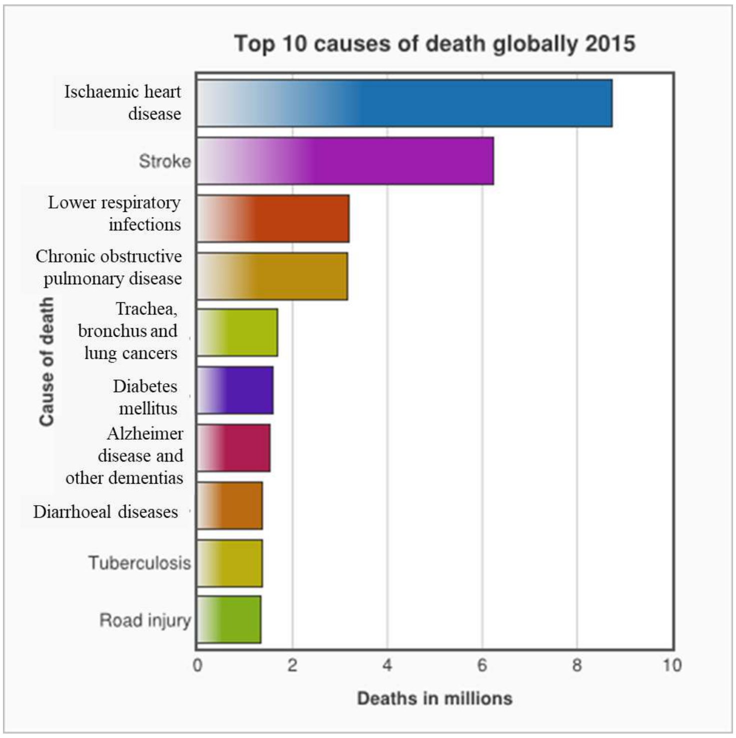

Figure 1. Survey from the World Health Organization (The World Health Organization, 2017)

In order to restore, even partially, movements and limb functions, there are several conventional rehabilitation procedures, many of them suggested by the Ministry of Health; one of them is the treatment of the upper limbs through repetitive active movements to restore the skills of hands and arms. This classical approach requires manual interactions between patient and therapist and treatment protocols entail daily sections for several weeks, which makes the procedure tedious and may be demotivating as argued by Krebs, H.I., et al. (1999), Barreca, S., et al. (2003) and Volpe, B.T., et al. (2002). In addition, conventional methods are limited to the therapist's ability, qualitative assessment of performance, and to patient progress, which is subjective because few quantitative measures are available and therefore have few results (Lum, P., et al., 2002).

As a tool to improve rehabilitation processes, technology-assisted therapies (TATs) have stood out among innovations in the area due to their capacity of reprogramming, repeatability, accuracy, as well as access to measures of amplitude, speed and acceleration of movements and measures of force and energy expenditure. Robots, as an example, allow standardization of therapeutic protocols and quantification of measures, which implies the reduction of qualitative factors in the interpretation and evaluation of the results of rehabilitation procedures. However, most of the available systems focus on recovery through repetitive motions of specific limbs or even single joints.

Despite the advantages quoted above, few of these devices have addressed the training of bimanual tasks, which are essential in our daily lives. Recent researches have shown that the hypothesis that cooperative movements are reintegrated automatically with the rehabilitation of the affected limb has not been proved so far. According to Nick, S., et al. (2004), in general, patients either avoid such activities, resulting in loss of bimanual functions, or reestablish new strategies to perform them, even if partially.

Rehabilitation by means of bimanual exercises is also justified by neural reasons. In the brain of a healthy person, there are regions located in the motor cortex intended for the left and right movements of the body, individually. In addition, when one activity requires the use of both parts of the body, another region is triggered; called the corpus callosum, this structure has the function of intercommunication between the hemispheres to act harmoniously (National Organization for Disorders of the Corpus Callosum, 2014) , as shown in Fig.2. Therefore, more attention should be given to ensuring that these motor memories are also reestablished and strengthened in functional training.

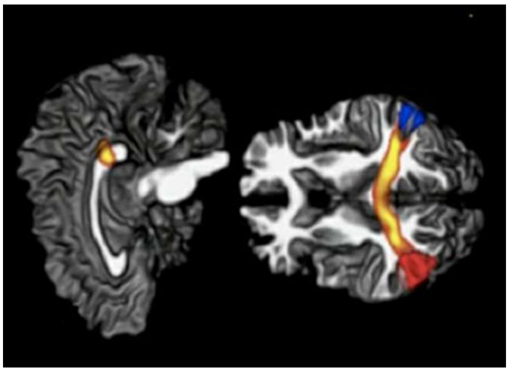

Figure 2. Interconnections between the brain hemispheres with an emphasis on the corpus callosum (yellow) creating the bridge between the left motor memory (red) and the right motor memory (blue) (Ciência Hoje, 2014)

In fact, current studies (Sainburg, R.L., et al., 2013, Johnson, M.J., et al., 2011 and Maciejasz, P., et al., 2014) suggest that the inclusion of bimanual training together with the provision of visual and tactile feedback are key factors in the advancement of TATs.

As a contribution for technology-based therapy, this work proposes a bimanual instrument and study its use in activities of motor functionalities recovery and further in conjunction with a greater rehabilitation system, SITAR, presented in sequence. Information about the dynamic forces and also the positioning of hand and arms involved during an exercise are essential to analyze the progress of a patient in a rehabilitation process and the strategy adopted to gather those data is detailed in section 3, Experimental Procedure. Session 4 addresses the results of the work to date, presenting the experiment conducted that lead to such outcomes. As a closure, session 5 summarizes the work presented and discusses the potential of the research and data collected from the initial proposal and predicts future interventions and improvements.

2. SITAR SYSTEM

Based on the needs presented previously, a rehabilitation system was recently developed, whose focus is directed to the execution of tasks, being uni or bimanual, for training and assessment of patients.

The Human Robotics Group from Imperial College of London, in partnership with the Laboratory for Functional Analysis and Technical Assistance (LAFATec), the Mechatronic Group of UFSCar and the Robotics Center of USP/São Carlos are working on the continuation of an innovative project proposed by Dr. Etienne Burdet for the recovery of movements of upper limbs of the body. Named as System for Independent Task-oriented Assessment and Rehabilitation (SITAR), this system is composed of a touchscreen table that can measure the forces of interaction and positioning integrated with intelligent objects. Instead of interacting with a virtual environment like most robot assisted therapies, patients interact with real objects, simulating the execution of daily tasks through computer-controlled games. Thus, this system can be used in the rehabilitation of uni and bimanual movements using appropriate tactile and visual feedback and dedicated assessment as presented by Randazzo, L., Burdet, E., Mace, M. (2014).

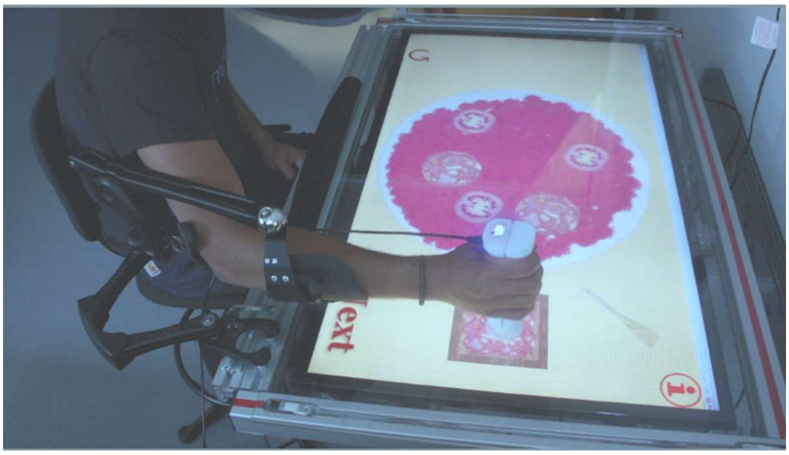

Figure 3. SITAR being tested by a healthy user playing the PizzaGame

The instrumented objects of SITAR are responsible for kinetic and dynamic measures, after all a robot is not able to reproduce the contact and movement interactions with as much precision as a real object (Roby-Brami, 2017, Burdet, E., et al., 2012. and Burdet, E., Balasubramanian, S., Klein, J., 2010), and it has the advantage of being sensitized, thus having its feedback as a way to evaluate user progress and integrate/communicate with games.

Among the developed games, the PizzaGame aims to emulate the task of assembling a pizza. In one of the stages, it is necessary to open the dough with the aid of a bimanual module similar to a kitchen roll. So far, the first prototype of such an instrumented module has been developed and is presented in this work.

3. EXPERIMENTAL PROCEDURE

The objective of this work is to develop an intelligent bimanual instrument capable of measuring contact and prehension forces in a rehabilitation training performed by a patient with motor deficit in the upper-limbs. The instrument also has to represent an object of the daily routine in order to simulate a regular task known by the user. As the focus obtain cooperative movements with the object, the user must use both hands to manipulate the instrument to fulfill the task.

A dough roll was the chosen object to replicate into an intelligent instrument so it satisfies all the requirements of the bimanual study and also already has a game designed for its use in SITAR, the PizzaGame. But instead of rolling, the object would slide over a table for the execution of the activities in order to simplify the acquisition of the forces involved. In this case, there are two main forces in interest for the study: the gripping force and the interaction force between the instrument and the table.

One of the most traditional force transducers is the load cell. Its operating principle is based on strain gauge as on resistor of wheatstone bridge. The application of a load generates a deformation in the material and consecutively in the strain gauge, changing the resistance of the bridge and consequently the output voltage in the signal reading. The data provided by it is very reliable, since the resistance bridge is adhered to a piece of metal designed to undergo a linear deformation with high accuracy of measurement and almost no hysteresis. This sensor captures the force only in one direction, usually pointed by an arrow on the side of the metal, so it must be aligned with the force to be measured.

Because it is a bimanual object, two load cells are required for gripping force measurements, one for each hand, and two to measure the vertical forces interaction between the table and the object, this force is the sum of the object weight and vertical forces applied by the user arms. Figure 4 schematizes the arrangement of the load cells and the actuation of forces in the instrument that mimics a dough roll.

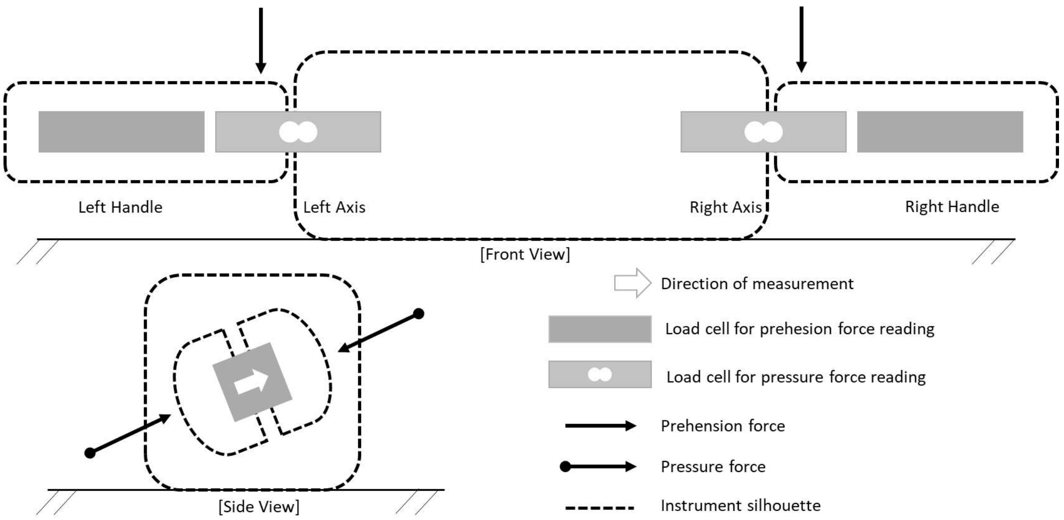

Figure 4. The physics in the instrument

4. MATERIALS

The load cell model CZL635 was selected for use in the instrument; it has a maximum weight capacity of 20 kg with a rated output power of 1 mV/V along with a 1000 gain operational amplifier of analogue signal. The Arduino Nano would be used for digital acquisition with a 10-bit resolution and data rate of 100 Hz.

The data transfer and communication is also important for the instrument use as a controller of games and progress control, thus it is be realized by a Bluetooth module, model HC-05, that operates at a radio frequency of 2,4 GHz. All the data is transferred to a personal computer and digitally stored.

5. PROTOTYPING

Once the electronic components to be used were defined, a software CAD was used for the mechanical design of the instrument and prototyping was performed through additive manufacturing of ABS plastic using a 3D printer from Sethi, model AiP A3.

The printed parts of the instrument were mechanically tested in order to conceive the best model for use in the first trials. Figure 5 shows the computer model, on the left, and the prototype fabricated on the right.

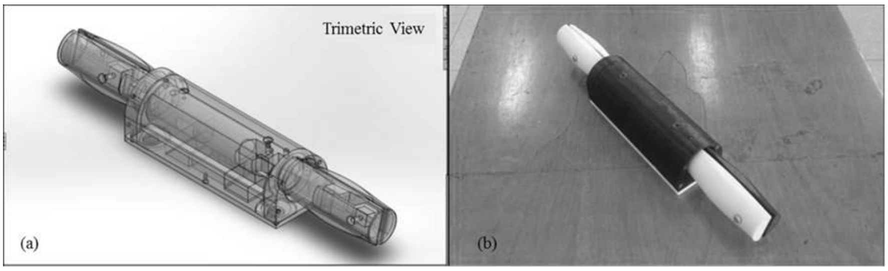

Figure 5. Prototype. (a) Design (b) Manufactured

6. PROGRAMING

For calibration and programming, the Simulink module from MatLab software was used according to the following task block shown in Fig. 6. By the start of the program, the load cells must be zeros to make their readings equal before any force is applied over them. Then, the data reading shall begin and from them, a live chart will show up to follow the measures and, in parallel, the collected information will be sent by Bluetooth to any other device connected, for example, to communicate with a game or simply gather the information to a data base.

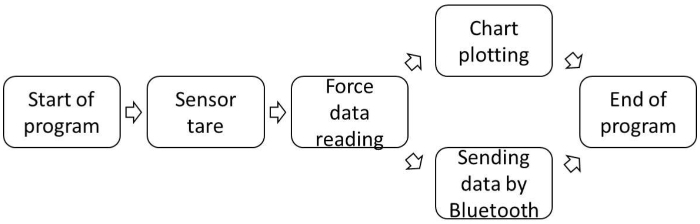

Figure 6. Summary of the testing program developed

7. PILOT EXPERIMENT

The first trials involved four authors of this work, one female and three males, aging between 23-35-year-old, all right-handed.

The pilot experiment required the authors to perform an exercise divided in two movements. In the first, the volunteer was invited to execute an elevated force for a short period of time by a guidance signal and then return to the neutral state without any effort acting on the object. In the second moment, the selected task intend that the should should move simultaneously, applying cooperative forces in a cyclic movement of pulling and pushing the object on a table for ten times, similar to the movement of opening a pizza dough.

8. RESULTS AND DISCUSSION

From the pilot experiment conducted with the authors, the results are presented in the form of graphics below shown by Fig. 7, Fig. 8, Fig. 9 and Fig. 10. It is important to observe that in all charts there is a presence of a high signal peak in the beginning due to the first movement, a pause and then an oscillatory pattern ending the set of movements required in the experiment.

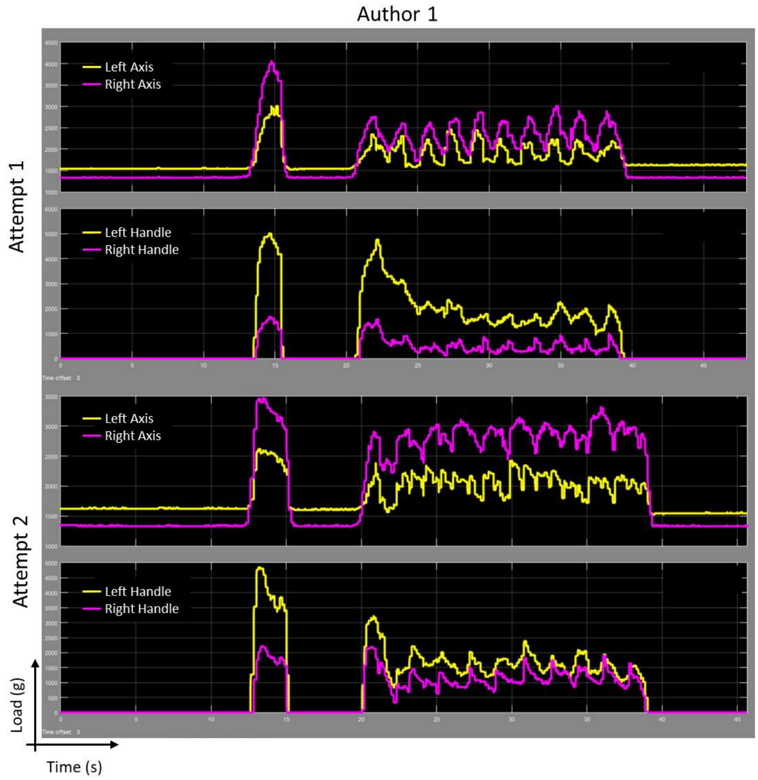

Figure 7. Experimental chart from author 1

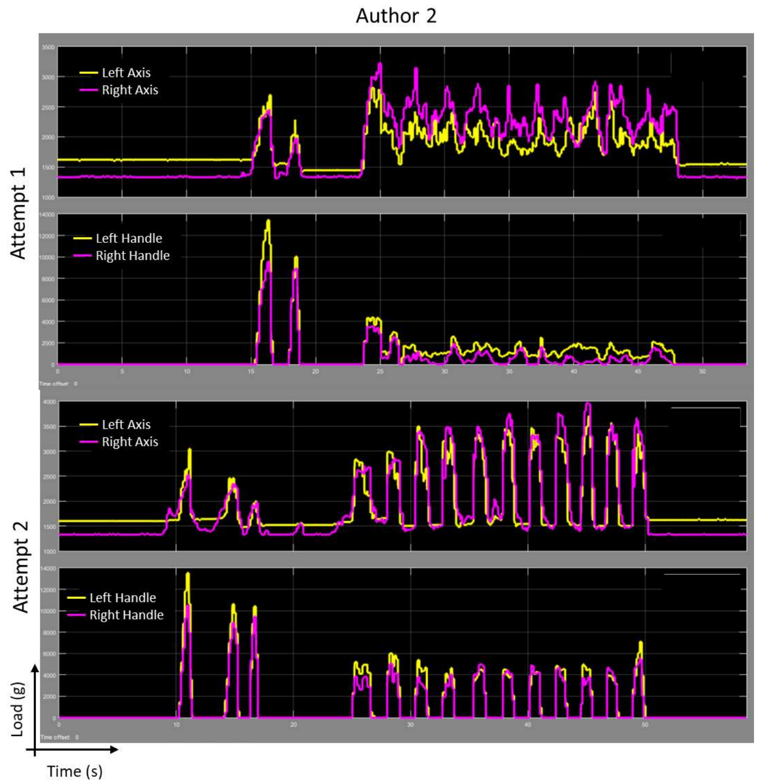

Figure 8. Experimental chart from author 2

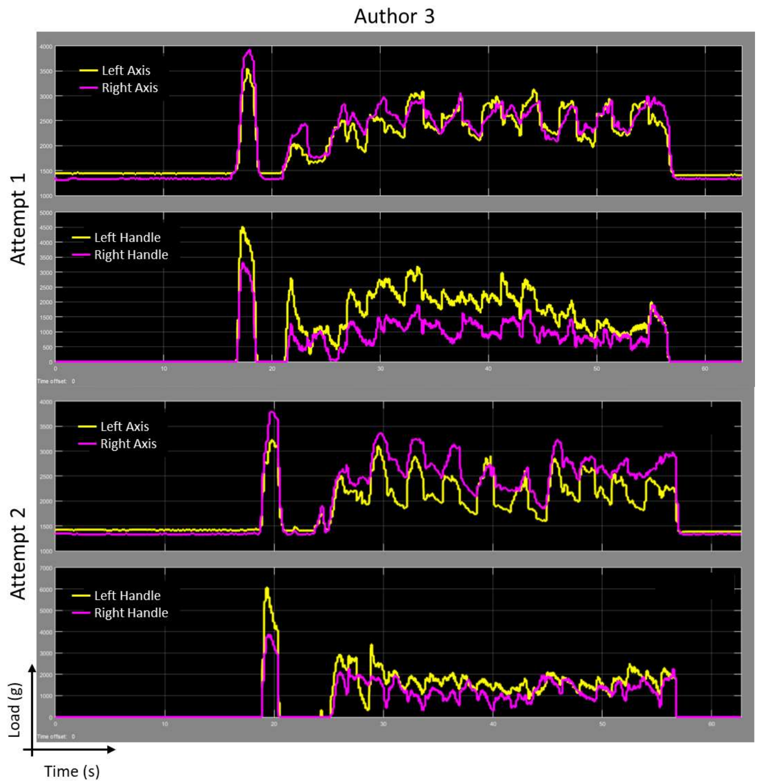

Figure 9. Experimental chart from author 3

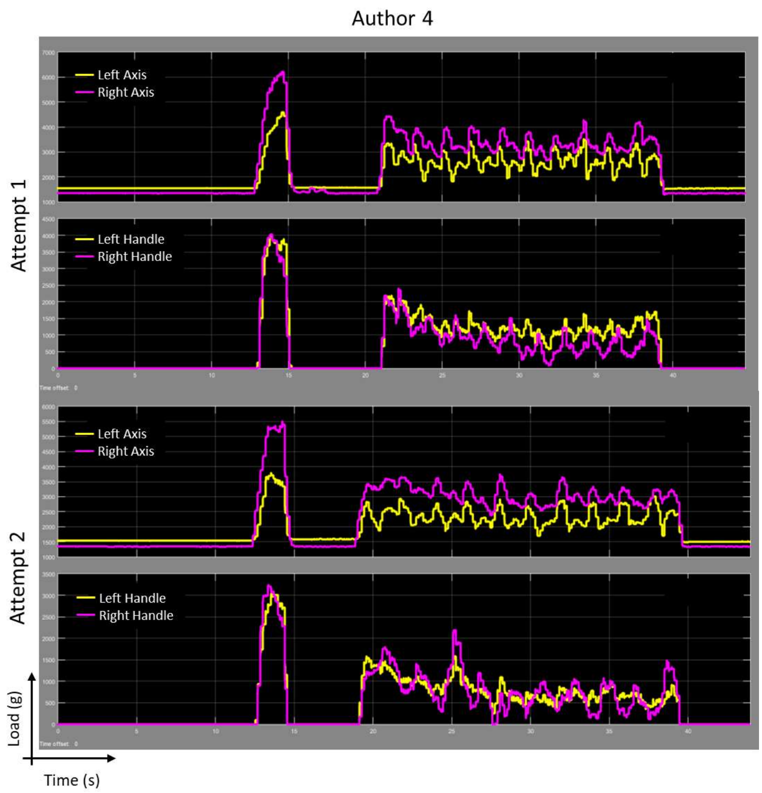

Figure 10. Experimental chart from author 4

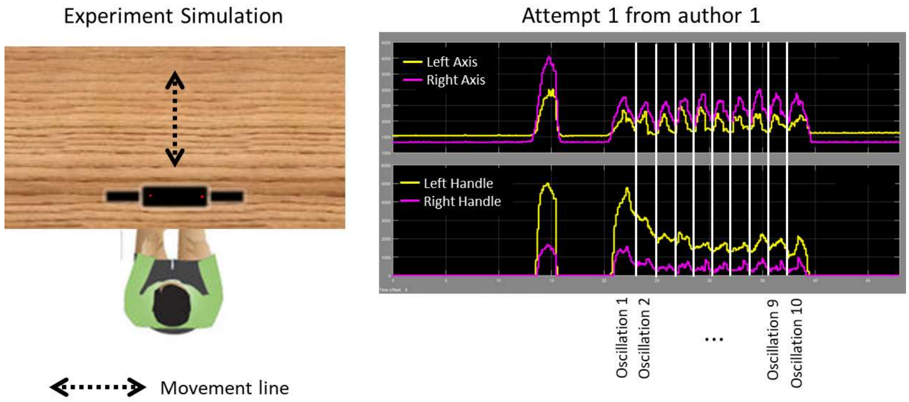

Figure 11. Experiment: simulation and analysis

The first chart of each participant attempt presents the signal form the load cell measuring the vertical forces, while the second chart is about the forces on the handles.

The vertical force signals are easier to notice during each moment of the oscillation because they have a better-defined trace, so that ten peaks can be seen for all graphics of all participants, consequently, it is possible to separate each oscillation as detailed in Fig.11.

For this first analysis, it is conceivable to imply that, although the wave profiles are characteristic of each individual, the behavioural pattern of the applied forces tend to be the same. Furthermore, further analysis that may be considered are related to the gripping force applied to the handles which usually tends to be high right at the beginning of the first movements and decreases over time to become more stable during the task. This occurs because the individual himself unconsciously tries to find the ideal strength point to perform the activity without wasting effort in a learning process.

9. CONCLUSIONS AND FUTURE WORKS

The purpose of this work was to develop an intelligent bimanual instrument in order to study the implications of cooperative tasks for rehabilitation therapies of motor functionalities of people who suffered stroke or other diseases that cause motor deficits in the upper limbs.

Even in the initial stages of testing, the conceived module proved to be suitable for the studies and revealed potential of use in integration with SITAR or as a general instrument for forces acquisition and further assessment in rehabilitation process.

From the data, it was possible to notice that there are kinetic patterns and force profiles susceptible to a deeper investigation in order to provide relevant information in the approach of more efficient methods for upper limb motor functional recovery, especially related to the creation of new strategies in the execution of tasks by the user and consequent reinforcement and development of the brain interconnections responsible for the synchrony and harmony of the bimanual movements.

When used in conjunction with SITAR, the instrument can also have its positioning on the table traced during the execution of the activities, so that such information will add even more in the biomechanical analysis of the movement related to the data acquisition of extension, flexion and user reach, for example.

In addition, improvements are also planned for the instrument such as the insertion of a Inertial Measurement Unit (IMU), which will provide more sensitive data on the performance of acceleration during tasks and their derivatives. It is also intended to detec the movements of the object with Kinect and active markers (Pedro and Caurin, 2012). Another point being debated is in relation to the enhancement of the handle, which instead of measuring only a total resulting force, could present the rate of force application at each point of its area, thus creating a mapping force of the user's grip. Such an improvement would be rather interesting to analyze the fingers and hand regions of overload, as well as the grasping arrangement on the handle.

The modifications are already being considered for implementation in the device, as well as the application of a statistically based experiment that will involve healthy participants and patients with motor deficits in the upper limbs. Because it is a research involving human beings, it is necessary an approval from the Ethics Committee for the accomplishment of the studies. From this data collection, we intend to apply sample evaluation methods such as Principal Component Analysis (PCA) and Linear Discriminant Analysis (LDA) in order to present conclusions of a high degree of reliability.

10. ACKNOWLEDGEMENTS

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