Design of a low-cost wireless hand-oriented system for stroke patients

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Abstract

In the last years there has been an increase in the number of rehabilitation systems designed for the upper limb. This body part is usually functionally restricted after suffering a stroke, which is the main cause of severe disability in Spanish adults. This paper presents a device oriented to the hand's rehabilitation made of low-cost commercial components, designed for both clinical and home usage, and able to be implemented without requiring deep knowledge in the matter.

1. Introduction

The data surrounding the stroke disease are alarming: a stroke occurs every six minutes [1], the incidence of the disease is higher for individuals above 55 years and it is estimated that 23% of the population will be at risk of suffer it by the year 2050 [1]. The healthcare cost derived from its treatment already represents around the 3-4% of the annual health budget [2].

In 85% of the cases the upper limb movement is affected [3], so a greater number of rehabilitation systems are being developed with the purpose of recovering the functionality of this extremity. Examples of the good results obtained by these systems can be seen in this study by Colomer et al. [4], making use of the Armeo®Spring, and the one presented by Shin et al. [5], employing the device RAPAEL Smart Glove. There is a common pattern among some of these devices: to combine mechanical tools, that support and conduct the movements of the patient while performing an exercise, with a digital interface that poses objectives to the user while keeping a record of his or her activity, so that this information can be used to evaluate and track the progress precisely.

The system developed for this work is focused on the recovery of the hand's functionality. The device, coupled to a glove, registers the patient's movements (flexion-extension of the fingers, opposition of the thumb, flexion-extension and pronation-supination of the wrist) and a videogame regulates the difficulty of the exercises and provides feedback to the user. The movements of the hand are translated into mouse displacements and the fingers flexion into clicks.

This device is an improvement of a previous version developed for *Proyectos 1.* In this new version a Bluetooth connexion has been incorporated (thus avoiding the need for the user to be physically connected to a computer) and a new sensor has been included to characterize the force applied by the patient. Also, a new type of rehabilitation videogame has been designed.

The paper is structured as follows: in section 2, the hardware is explained; in section 3, the rehabilitation videogame is described; finally, in section 4, the main conclusions are presented.

2. The hardware

The first model of the device is based on an Arduino Micro microcontroller, a Pololu AltIMU-10 v5 inertial sensor and a pair of FSR sensors. These components are placed inside a 3D printed structure attached to a glove, over the part corresponding to the back of the hand, being one sensor located at the palm and the other one, at the thumb. The data are processed in the microcontroller, which sends them through a serial connexion by USB cable to the computer.

This previous version of the device had some limitations that have been faced for the development of a second model. The use of a glove as support of the electronic components, as well as the models of microcontroller and inertial sensor, have been kept. At the same time, the USB communication has been substituted by a Bluetooth (BT) connexion with the computer and the FSR sensors, by a load cell (Aihasd). The advantage of this new sensor compared to the previous ones is that it can characterize the amount of force with which the patient is performing. The model used is the SEN-13329 (Sparkfun Electronics), based in strain gauges, which can measure forces up to 200N. A HX711 amplifier acts as a conditioning system for the gauges, while also providing a digital value according to the force applied to the load cell. A 9V battery is used as power source. These changes are explained in the following subsections. A diagram of the new setup can be seen in figure 1.

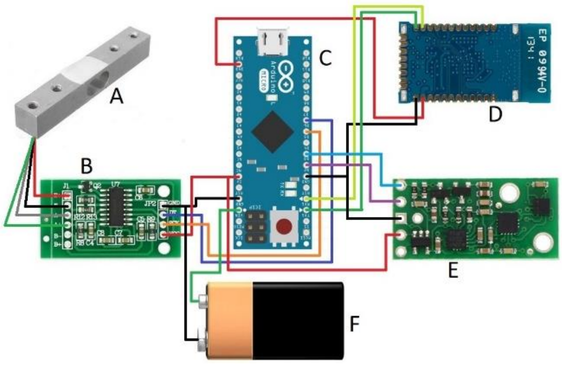

Figure 1. *Scheme of the electronics: A-load cell, B-amplifier, C-Arduino Micro, D-BT module, E-inertial sensor, F-battery.*

2.1. Bluetooth communication

The objective of this modification is to provide a greater commodity and freedom of movement to the user when performing his or her exercises. The USB cable is removed and the patient is not physically attached to the computer. A BT module is now responsible for communication between the user and the machine.

Due to the necessity to simulate clicks and mouse movements, the module employed must be able to operate in Human Interface Device (HID) mode. The model that has been chosen is the RN42. This module offers multiple HID connection modes, such as keyboard, mouse or joystick. For our purpose, we are interested in the combo mode, which makes the RN42 act both as a keyboard and as a mouse simultaneously.

When the user exceeds a certain force threshold when pressing the load cell, the Arduino sends a hexadecimal command through the BT connexion, which is interpreted by the computer. Similarly, the hand's angular position is periodically obtained, and the cursor adjusted accordingly through a raw command. Even if this way of transmitting data is slower than using a physical connection, the communication is still fast enough not to affect the use of the interface.

2.2. Load cell

As a previous step to its test with users, the linearity, hysteresis and repeatability of the sensor have been obtained. To do so, the data corresponding to fixed weights up to 10.620kg have been registered, whose results are shown in the following lines.

To test the linearity of the sensor and its sensibility to temperature changes, multiple measurements have been made at room temperature and at 41.6º C. This result is observed in the figure 2, which show a good linearity, almost unaffected by a high difference in temperature.

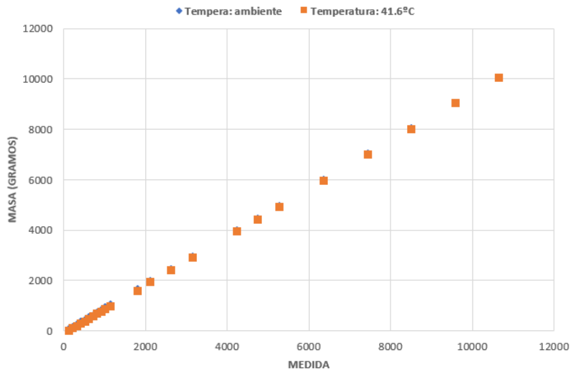

Figure 2. *Measurements from 110 to 10620 grams, at room temperature (blue) and at 41.6ºC (orange).*

The hysteresis value, obtained through equation (1), is of 0.37 and the repeatibility, of 0.00045279. The latter has been measured, following the method employed in [6], as the relative standard deviation (RSD), being this the mean from 1 to n (n=6 in this case) of the quotient of the standard deviation and the mean of six measurements of some weight$_i$. The equation used is (2) and the gathered data are displayed in Table 1.

$$\text{Hysteresis (\%)} = \left| \frac{(Y_{mn} - Y_{mp})}{(Y_{max} - Y_{min})} \right| x100 \qquad (1)$$

- Ymax: maximum common Y
- Ymin: minimum common Y
- Ymn: superior line's Y value for the X's median
- Ymp: inferior line's Y value for the X's median

$$\text{RSD} = \frac{1}{n} \sum_{i=1}^{n} \frac{\sigma(weight_i)}{mean(weight_i)} \qquad (2)$$

Weight	A	B	C	E	D	F
2100	2103	2100	2097	2097	2102	2099
4200	4204	4202	4199	4201	4203	4202
5260	5265	5263	5261	5261	5264	5263
6320	6323	6321	6318	6318	6323	6320
7380	7383	7380	7377	7377	7381	7379
8440	8438	8439	8433	8433	8439	8432

Table 1. *Six measurements (A-F) of six different weights.*

The obtained results reflect a good behaviour of the sensor in similar scenarios to its use in the interface. The employment of a load cell allows an accurate characterization of the force exerted over it, providing more data (compared with an FSR), to the therapist at the time of evaluating the patient's activity.

3. Rehabilitation videogame

A new videogame has been developed with Stencyl (as the one that accompanied the previous version of the device) to set exercises to the patient and regulate their difficulty.

The game simulates a basketball court, with a net and several balls, as can be observed in figure 3. To score a basket, the user must move the cursor, represented by a glove, up to a ball and then press over the load cell to grab it. Then, the patient must stay over the force threshold while the cursor is moved to the net and finally release the grip to score. When a certain amount of points is reached, the user enters a new level. The difficulty will rise by increasing the number of points needed to pass to the next level or by making the net mobile. This way, the difficulty is progressive and the user is kept motivated.

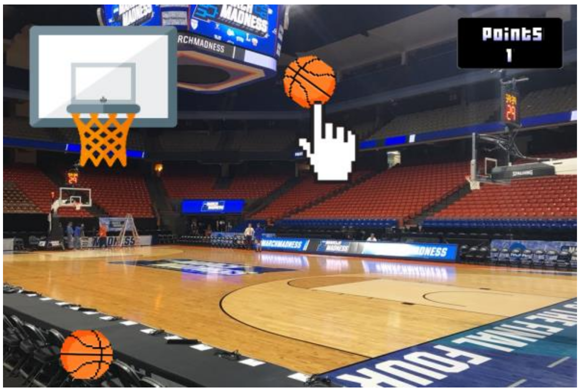

Figure 3. Example of one of the videogame's levels.

4. Conclusions

The interface's prototype was taken to the hospital Beata María Ana (Madrid), where it was presented to an occupational neurologist and a therapist. It was considered as interesting the possibility of employing the device in the patient's home, the possibility of controlling the videogame by performing typical rehabilitation movements, as well as measuring the frequency of pulsation. Besides, it was proposed to measure the force exerted by the user as a means of evaluation.

The developed system allows the realization and regulation of exercises of the upper limb that target the hand's movements. A user interface has been designed so that the patient is able to control a videogame, using the fingers and the wrist, in order that rehabilitation exercises are performed while providing a means of abstraction and motivation. The interface is wireless and able to characterize the force exerted by the user, an information of clinical interest.

The final price of the device is slightly higher than its previous version's, around 90€. When compared to other systems available in the market, like the RAPAEL Smart Glove or the HandTutor or more complex orthosis systems like Armeo®Spring or the Gloreha Workstation. The developed prototype is presented as a rehabilitation tool opened to any professional or patient to be implemented and used for a low cost.

The microcontroller's code, the 3D printing models, the videogame and the electronic diagrams have been uploaded to a GitHub repository [7], so they can be used by interested anyone.

Currently, it has been only used by healthy subjects. As future work, it is expected to test the device in stroke patients in the hospital Beata Santa María. In this way, medical and patient feedback will help to improve the system and adapt it to those exercises and measures of greater clinical interest. Besides, the usability of the interface will be studied as well as its performance which will be compared to the widely used HandTutor.

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References

[1] Web page of the Federación Española de Ictus (FEI). https://ictusfederacion.es (Accessed: Diciembre 2017).

[2] Martínez-Vila E, Irimia P, Urrestarazu E y Gállego J. El coste del ictus. ANALES Sis San Navarra 2000; 23 (Supl. 3): 33-38.

[3] Web page of Red Menni. dañocerebral.es (Accessed: Diciembre 2017).

[4] Colomer C, Baldoví A, Torromé S, Navarro MD, Moliner B, Ferri J, et al. Eficacia del sistema Armeo®Spring en la fase crónica del ictus. Estudio en hemiparesias leves-moderadas. Neurología 2013; 28:261-7.

[5] Shin, Joon-Ho et al. Effects of Virtual Reality-Based Rehabilitation on Distal Upper Extremity Function and Health-Related Quality of Life: A Single-Blinded, Randomized Controlled Trial. Journal of NeuroEngineering and Rehabilitation13 (2016): 17. PMC. Web. 31 Dec. 2017.

[6] García, J. F. et al., Obtención de Repetibilidad, Histéresis y Linealidad de un sensor de flexión resistivo por medio de un instrumento virtual. Universidad Autónoma del Estado de México, México

[7] Ignacio Martínez Capella, Upper Limb Rehabilitation Interface with Arduino, (2018), GitHub repository, https://github.com/nachomcapella/Upper-LimbRehabilitation-Interface-with-Arduino