Digital Dynamometer: A New Technology to Measure the Palm Grip Force-Time Curve

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Abstract. The palm grip measurement is helpful in upper limb rehabilitation. This paper focus on the presentation of a new technology to measure palm grip and show graphically the Force-Time response. A hand Digital Dynamometer was partially developed using load cell techniques. Its mechanical design will follow a commercial equivalent tool; its interface communicates with dynamometer hardware and its program has been developed for both Android and iOS operational systems. The load cells do not have accuracy error after calibration, proving to be better over other technologies. The devised solution will help physiotherapists monitor their patients in upper limb rehabilitation programs.

Keywords: Palm grip · Dynamometer · Load cell · Force-time · Finger force

1 Introduction

To determine the effects of different procedures or the effectiveness of different treatment strategies for health conditions that affect the upper limbs, especially hands, a reliable and valid assessment of grip strength is needed. Measurements of hand grip strength and pinch grip are pointed out as indicators of the functional status of the upper limb. The Jamar dynamometer is considered the most acceptable and accurate commercial device to measure hand grip [1]. Other projects aimed to reduce the production cost and maintain the same measurement qualities for palm grip [2–4] and [5]. In these works, the designers used several Force Sensor Resistor—FSR distributed along the cloth gloves. Each project adopted a specific way in sensors position, but in general, they were put on the hand phalanges so the values of force in different hand grip modes could be recorded.

Basically, FSRs are sensors composed of a semiconductor ink placed between an electrical contact and a thin layer of polyester. Its resistance varies according to the pressure applied to this structure. The variation is inversely proportional, i.e., the greater the pressure on its surface, the lower its resistance [4]. There were positive points linked to the use of FSR: the possibility of measuring the force that each finger exerts during the palm grip; the ability to adopt a variety of object grips, including pincer grips, and easy replacement of components due to low cost. Some problems were identified

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by these researchers [2–5]. The systems could not make absolute measurements, but only relative ones. Over time, the sensors began to deform, which implied long-term reliability. Calibration issues have been identified. Finally, contact problems between the sensor and the surface of the object to be picked up made it difficult for the user to measure real force.

More recent works have used strain gauge transducers, also encapsulated in load cells. This kind of sensor has high precision, and the designed devices can be applied to cylindrical gripping activities [6, 7]. There are differences between these two types of technology, FSR and strain gauge; according to [2–5], FSR sensors allow several types of hand grasping and individual finger force measurement, while [6, 7] pointed out that strain gauges allow only one type of hand grasping and force measurement of the five fingers together.

In view of the problem with the use of FSRs, and the cost of commercial dynamometers, this article aims to present the construction of a digital dynamometer capable of recording the strength values of each finger over time during the palm grip of user. For this, some requisites were defined to be achieved during its development: (i) being able to perform the acquisition of strength data from the individual's fingers individually for each finger; (ii) to calculate the handgrip strength for these users based on the acquisitions made by the sensors; (iii) to show a high degree of precision; (iv) to have a graphical interface to present force versus time data for all fingers individually and together if the user requests it; the program should export the data file if the user deems it necessary; (v) graphical interface for cell phones, so that the user can assess the Force-Time curve generated by the handgrip force.

It is expected that this device will be a support tool for physiotherapists and researchers, and that new rehabilitation assessment strategies will be adopted from this new instrument, benefiting several health professionals and their patients.

2 Methods

2.1 Electrical Design

Due to the adversities found in the literature, the dynamometer was developed using 20 kgf load cells (Aeph do Brasil). A load cell can be composed of an aluminum bar with four Strain Gauges glued to the central part of the bar. These four elements have a value of 1 kΩ and are connected in a Wheatstone Bridge configuration, in this structure, two Strain Gauges are connected in a compression configuration and the other two in traction; thus, avoiding drift caused by temperature [7].

Five 20 kgf load cells will be used to manufacture the device. These load cell values were adopted to oversize the system, observing the average value of 462.61 N taken from [8], where a Jamar dynamometer was used to find the palm grip value of a population separated by age group, in which the highest value of palm grip was used, adopting a safety tolerance. Five 20 kgf cells would add up to a total of 100 kgf-system measurement; converting this value to [Newtons] one gets 980.665 N. That way, the load cells will not be overloaded.

Each cell will individually measure the force exerted by each finger; together with the cells, five boards with CI HX711 are connected; it is a commercial electronic circuit used as an interface for industrial load cells, being able to perform signal acquisitions at 80 Hz, with sufficient sampling rate considering the human movement speed [9]. The HX711 is a 24-bit analog to digital converter (ADC), produced by AVIA Semiconductor; it will be responsible for converting the load cell deflection value and sending the value to the microcontroller.

The resolution of a 24-bit ADC converter is optimum. First, we need to calculate the ADC Number of Steps (NS) through Eq. (1). Then, the Step Scale (SS) can be calculated from Eq. (2); where the Step Scale is the quotient between the maximum value recorded by the load cell and the number of steps of the ADC.

$$\mathrm{NS} = 2^{n} bits = 2^{24} = 16,777,216 \tag{1}$$

$$SS = \frac{LCmax}{NS} = \frac{980.665}{16,777,216} = 0.000058452\,N \tag{2}$$

As can be seen, the 24-bit ADC converter is able to detect variations of the order of 58.45 μN, ensuring high resolution and accuracy in the measurement of each finger.

The microcontroller adopted in this device is the ESP32. It is a powerful low-cost microcontroller, manufactured by the Espressif Company. This device has a dual-core Xtensa LX6 processor with 520 kB of SRAM [10]. Using ESP32 has some advantages: (i) it is easy to implement algorithms using this tool, as it is not necessary to enable registers as in other microcontrollers; (ii) several libraries are already made available by the manufacturer, without the need to implement their functions; (iii) low cost, and (iv) programming does not require cabling, if any, the algorithm updates occur wireless (Wi-fi and Bluetooth).

An algorithm in C/C^{++} was coded and compiled on the ESP32 microcontroller. This algorithm is responsible for requesting data from the HX711 circuits and waiting for the data response. The calibration of the load cells is performed via software, and the program compiled in ESP brings the cell configuration parameters.

An interface for cell phones has been developed for the Android and iOS operating systems, and this application will communicate with the ESP32 via Bluetooth. This interface displays the force values along time on the mobile screen. The individual curves of the fingers and the sum are available, making it possible to export all the files generated by the application to the cell phone's memory. The data record format will be in ".txt" or ".csv".

Figure 1 illustrates the block diagram of the project.

2.2 Mechanical Design

For the mechanical dynamometer design, the system called DIGI-FLEX was used as a reference, developed to perform hand strengthening exercises. The system consists of a central bar with several springs positioned on opposite sides of this bar. On one side the springs are attached to four individual plates, on the other side the springs are connected to a palm support. There are several devices following this model, varying the resistance of the springs to increase the intensity of the exercise [11]. In Fig. 2, an example of these DIGI-FLEX models is illustrated [12].

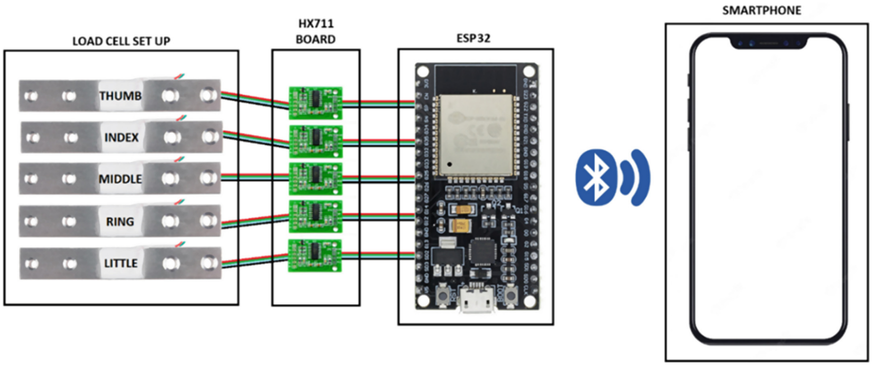

Fig. 1. Block diagram of digital dynamometer.

Fig. 2. DIGI-FLEX model [12].

For the development of the dynamometer, ergonomic aspects and the mechanical design focused on palm grip were taken into account. Firstly, a modeling was carried out using SolidWorks® software to represent the first prototype, following the anthropometric dimensions indicated in equivalent products. In Fig. 3, the project under implementation is illustrated in isometric perspective.

2.3 Load Cell Calibration

Initially, the five load cells were calibrated. For this, they were mounted on a test bench as shown in Fig. 4. After fixation, a test algorithm was developed to run on the ESP32 to calibrate each one of these five cells. An object with a verified mass of 1500 g is placed on a plastic support. The support is screwed into a load cell while the cell is fixed on a test bench so that there is no movement during the experiment. When placing the object on the structure, there is a deflection in the cell structure, then the ESP32

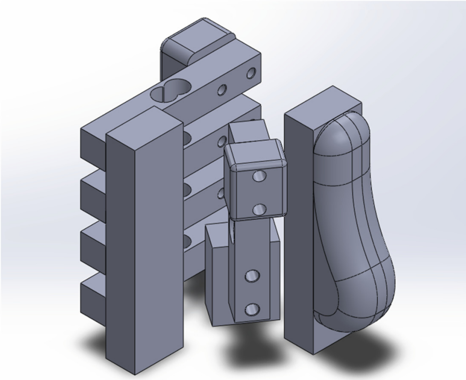

Fig. 3. Isometric perspective from dynamometer model.

performs a sampling of values sent by the HX711 circuit, with 80 samples per second for the maximum reading scale.

Fig. 4. Mass of 1500 g choose for calibration.

2.4 Ethics Committee

For the next steps, a first prototype will be assembled with 3D parts so that the grip of the device can be assessed. Then there will be adjustments in some pieces allowing any anthropometric characteristics to be adopted in the use of this project. An adaptation of the parts that are in contact with the fingers will be carried out. A snap-in format will be used, allowing the device to be compatible with any individual's hand. Then, it will finish the development of the mobile application.

The device will have as a differential for the existing dynamometers the fact that it presents the force data along the time for all five fingers individually and allows the export of the data in the form that the user deems necessary, from the cell phone to some file ".txt" or ".csv", that could be used to find aspects about upper limb condition.

For experimental evaluation, 20 participants will be selected, between 18 and 60 years old, recruited through public notice on the PUCPR campus. The inclusion criteria are:

- Full motor skills in at least one of the upper limbs.
- Signing the free and informed consent form.

Participants to whom the following criteria apply will be excluded from the study:

- People with cognitive disorders that prevent understanding of the experimental assessment.

For the execution of the experimental stage in vivo, the experimental protocol will be submitted to the PUCPR's Research Ethics Committee.

3 Results

Experimentally, only the individual calibration parameters for each load cell were obtained and it may be observed in Table 1.

Table 1. Calibration factor for each load cell.

Load cell	Calibration factor
Thumb	108000
Index	104000
Middle	106000
Ring	107000
Little	107000

The Calibration Factor is a scale number inside the microcontroller, that helps to represent the real value of mass measured. This value can be modified to compare the real value and the measured value. ESP32 generated a data output of 80 values with two decimal places referring to the mass of the object in question. Equation (3) can be used to calculate the accuracy, where RV is the real value of the object's mass and MV is the value measured by the microcontroller.

$$Error(\%) = 100(MV - RV)/RV \tag{3}$$

The analysis of the accuracy of the load cells can be seen in Table 2, where the error values for all measurements were calculated. It can be noted that no errors were found for all 80 samples recorded by ESP32, the average value of the actual weight is 1500 g, the mean value of the measurement is 1.50 kg, and the mean error value is 0%. It is possible to interpret that load cells can perform exact measurements.

It can be observed in Table 3 the values presented in other studies, regarding the measurement error after calibration of the FSRs.

Table 2. Load cell precision calculation.

Sample (n)	Real value (g)	Measured value (g)	Error (%)
1	1500	1.50	0
2	1500	1.50	0
3	1500	1.50	0
…	…	…	…
78	1500	1.50	0
79	1500	1.50	0
80	1500	1.50	0

Table 3. Error value after calibration from other studies.

Reference paper	Error after calibration (%)
First type FSR [4]	6.3
Second type FSR [4]	10
Third type FSR [4]	13
Single FSR [5]	4.5

4 Discussion

The load cells are working correctly, and the measurement accuracy of the load cells is superior when compared to the values of the FSRs, it is essential to assemble the first prototype to verify every ergonomic issue of this project, new adaptations need to be carried out to cover all hand shapes. To measure the grip of both hands, it is necessary to make two devices, one for the right hand and one for the left hand. An important point of improvement is to add another load cell and reorganize the structure to use a single device, because in the current structure, a device is needed to measure the strength of the right hand and another device for the left hand, with a prototype performing the measurement on both hands will reduce the cost of your production.

No studies were found capable of measuring the strength of each finger individually during palm grip using load cells. The most recent studies found are prior to the year 2010, using FSR [2–5], and found adversities such as difficulty in calibration, lack of adherence in gripping objects and loss of system reliability during use. In the case of load cells, there is no difficulty in calibrating the model presented, the values found are accurate and there is no problem of lack of contact during the palm grip. The positive factor of those four projects is that they do not need a device to perform the grip measurement, as wearing the glove it can test different gripping methods. A negative factor about the model using load cells is that their measurement will be limited to the palm grip forces.

5 Conclusion

The set of load cells is more accurate and effective than the systems addressed with FSR. The extraction of the force curve along time will provide new insights into the characteristics of muscle strength, aid in specific tasks helping physiotherapy professionals and their patients, new treatment strategies for the upper limbs and the assessment of impact of the rehabilitation treatments. Its use in future researches for upper limb rehabilitation is estimated.

For the digital dynamometer in development, it has been implemented an instrument with ergonomic design, which will serve all subjects, regardless of hand size. It is expected to obtain a large scale precision tool that remains calibrated on the long term, an easy-to-use device and that can meet new project demands. It is expected to transfer the developed dynamometer to the industrial sector, so that it can benefit a large number of professionals and their patients. It is hoped that it will serve as a support tool for physiotherapists and researchers, and that new rehabilitation assessment strategies may be adopted from its use.

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Conflict of Interest
The authors declare that they have no conflict of interest.

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