Hand Assessment Device Prototype

Sabrina Sofía Prieto Salazar(✉), Guadalupe Karla Velasco Gómez, Perla Vanessa Aguilar Mejía, and Marisol Martínez-Alanís

School of Engineering, Universidad Anahuac Mexico, 52786 Huixquilucan, Mexico
sofi.prieto.salazar@gmail.com

Abstract. The assessment done during physiotherapy is a critical step, since it provides information needed to determine the best possible treatment for the patient. Specifically, hands are essential tools for humans; reason for which developing limitations causes a significant drop in patients' quality of life. As a result, it is necessary to have tests that record patients' development in quantitative terms, independent of the physiotherapists' interpretation.

Nevertheless, the instruments used for the task possess limitations that lead to errors during the assessment. Hence, the aim of this work was to develop a device capable of measuring the range of motion (ROM) and grip strength, simultaneously.

To fulfil the project's objective, force and position sensors were analysed, resulting in the selection of the FSR400 for strength and P090 for ROM measurements. All sensors were calibrated to obtain the correct units (Newtons and degrees). Subsequently, the interface was developed using NI LabVIEW. This software allows for fast analog data input and processing, using specialised data acquisition devices (DAQ).

Tests for adjustability and accuracy were taken to ensure the correct behaviour of the prototype. Accuracies of 81.62% in ROM and 52.47% in grip strength were found, demonstrating its overall functionality and possibility for improvement.

Keywords: Hand Assessment Device · ROM · grip strength · sensors

1 Introduction

Rehabilitation is the process that allows patients to recover, maintain or improve their basic abilities to perform daily activities that have been diminished as a result of an accident, disease or as a side effect of medical treatment. Physiotherapists are the health professionals that provide patients with these rehabilitation processes and their corresponding assessments, assisted by diverse devices and equipment as needed [1].

In physiotherapy, the initial assessment refers to the dynamic process [3] implemented before starting the patient's rehabilitation. During this stage, all the information required to determine an adequate rehabilitation process is acquired through anamnesis and physical exploration [2]. The developed process must be customised to the patient's needs and objectives, based on realistic goals that suit the patient's lifestyle and context [4].

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This is why it is essential to have updated functional testing according to the patient's pathologies, particular needs and characteristics, as well as adapted in order to make comparisons among devices and to analyse their progress based on the treatment provided [5].

On the other hand, human beings are in constant use of their hands, since these are indispensable to perform basic daily activities. Consequently, if there is a problem in one or both hands, their quality of life will be negatively affected.

There are various pathologies that affect the hand's motricity, the most frequent ones being tendonitis, rhizarthrosis, hand arthrosis and sprains, carpal tunnel syndrome, as well as traumas, concussions, arthritis and cardiovascular accidents (CVA) [6]. Any of these can have a detrimental effect on the way hands function, mainly changing their range of motion (ROM) and the amount of pressure that can be exerted.

As a result, there are several assessment devices that can be used to evaluate both measures, such as the dynamometer, the pinch meter, the vigorimeter and the goniometer. Nevertheless, these tools depend on the physiotherapists' ability to use and read them, therefore causing a lack of precision and continuity during the rehabilitation process [7].

Consequently, there is an increasing necessity of developing new devices that satisfy the acquisition of these measurements while providing an increased accuracy and a shorter evaluation time, improving the overall process, for both patients and health professionals. Some devices have been developed that aim to measure either force or ROM separately [8–10]. However, there is no device capable of obtaining both measures simultaneously at low cost.

Due to this, the Hand Assessment Device prototype (HAD) was developed.

2 Materials and Methods

2.1 Materials

For the development of the HAD prototype, two sensors were used. Firstly, to measure force, it was determined that the appropriate sensors, due to their characteristics, would be the Force Resistive Sensors FSR400 (Interlink Electronics, California, USA), which meet the maximum dimensions considered to be placed on the fingertips (10 mm). These sensors cover the needed measuring range, with a resolution of 0.1 N and maximum sensitivity of 10^2 N, allowing force to be measured by decreasing electrical resistance as more pressure is applied. In addition, they have force detection resistors at their core, which are responsible for producing the reduction of the electrical resistance as they detect variations in pressure. Its operation is based on applying pressure in the measuring area so that the conductor allows the flow of electricity from one cable to another. Additionally, when the sensor is in a neutral state, the circuit will remain at rest and electrical current cannot pass [11, 12].

On the other hand, the choice of sensors for the measurement of ROM was the P090 rotatory linear potentiometers (TTI Electronics, Texas, USA). These sensors have an ideal size for being attached to the fingers (since the movements made by the joints of the hands are very small), as well as having a wide measuring range, and having the terminals in a lateral position (beneficial for the design of the device). In addition, the

slot on the knob will help in the adaptation of the sensor, allowing it to move at the same time and angle as the finger joints.

LabVIEW (National Instruments, Texas, USA) was used as the programming language.

2.2 Prototype Development

In order to develop the prototype, the methodology shown in Fig. 1 was followed. Firstly, a previous investigation was carried out to determine the needs of patients and professionals and existing commercial products. Subsequently, for the construction of the device, the sensors that would make the desired measurements were chosen, and the circuit and source code were built (Figs. 2 and 3). The sensors were calibrated, and the structure that would support the sensors was designed. Likewise, the materials were chosen to build said structure, and the components assembled. Finally, the prototype was tested and the necessary corrections were made.

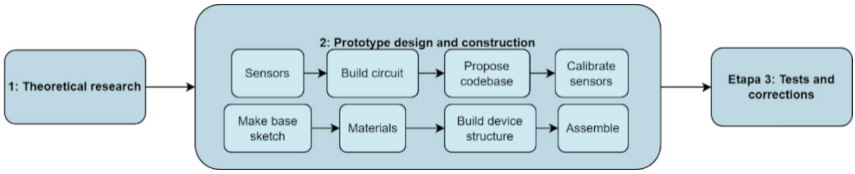

Fig. 1. Methodology followed for the development of the Hand Assessment Device prototype.

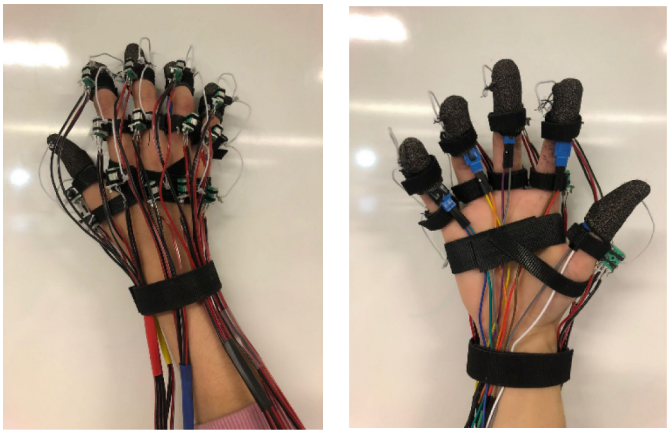

Fig. 2. Final assembly of the Hand Assessment Device prototype; back of the hand (left) and palm (right).

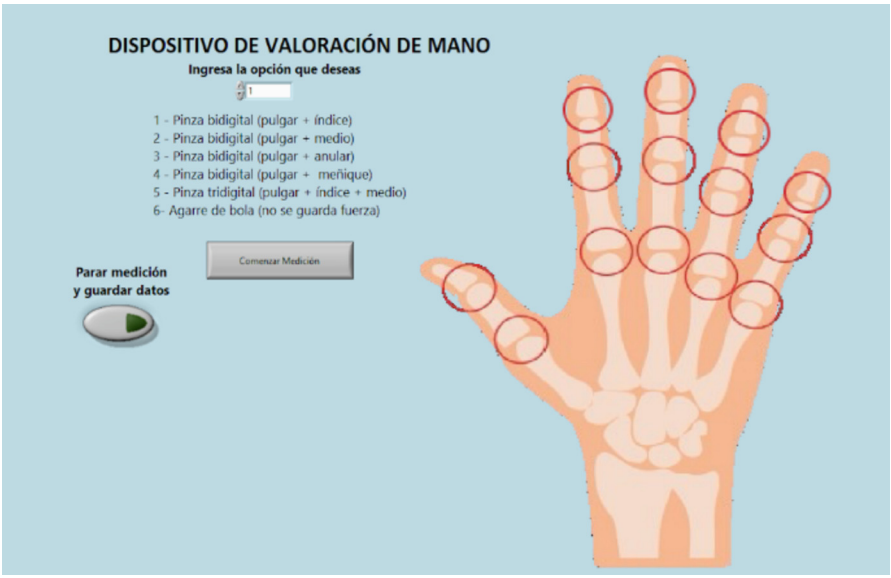

Fig. 3. User interface (LabVIEW).

2.3 Data Collection

To test the device's adjustability and accuracy, 10 subjects of different ages and sexes were asked to use the HAD in order to compare the results with those given by the references used to calibrate the sensors. Each one of them used the device on their dominant hand (all of which were measured), providing the ROM of three fingers (thumb, index, and middle) and digital strength of one pinch (thumb+index pinch).

Furthermore, the data obtained with the HAD and stated instruments was analysed in order to calculate the standard deviation to determine the device's accuracy. Additionally, a comparison of the measured hands was made with known data to determine the device's adjustability to adult hands.

3 Results

A total of 10 volunteers were tested in order to obtain the accuracy of the hand assessment device (Tables 1 and 2) and its adjustability to different hand sizes (Table 3).

The device's accuracy was determined by the following Eq. (1), based on a statistical analysis of the data.

$$\text{accuracy} = (1 - \sigma z) \times 100 \tag{1}$$

where,

σz = standard deviation of z.

z = (hn - xn)/xn.

xn = goniometer/GFT measurements.

Table 1. Accuracy and average data obtained from 10 different subjects using the Hand Assessment Device vs a goniometer.

Finger	Hand Joint	HAD [°]	Goniometer [°]	Accuracy [%]
Thumb	IP	36.85	43	83.62
	MP	11.993	16.8	61.52
Index	DIP	37.12	35.2	93.43
	PIP	61.28	58.2	90.47
	MP	8.23	10.9	71.45
Middle	DIP	37.23	36.4	91.78
	PIP	50.33	53	90.39
	MP	12.22	14.6	70.27

IP: interphalangeal, DIP: distal interphalangeal, PIP: proximal interphalangeal, MP: metacarpophalangeal.

hn = HAD measurements.

Table 1 shows the average degrees measured with the HAD compared with the average degrees measured with the goniometer. These averages were taken from each of the three fingers' joints.

Based on these data, it was possible to determine the accuracy presented by the device. The average accuracy for all joints in all three fingers was 81.62%. Said number presents the overall accuracy of the HAD in terms of ROM measurement, but as it can be seen, it varies depending on which joint is analyzed. These variations are expected since the HAD is still a prototype, with structural vulnerabilities that can affect the way in which it measures finger movement. Still, despite said area of improvement, the device proves to be accurate for ROM measurements.

Moreover, the device eliminates the inter-rater reliability, which may be poor depending on the physiotherapists' abilities when assessing the same individual, since it will perform consistently for each individual.

A similar prototype implemented inertial measurement units (IMUs) to measure ROM. Even though this device reported a small error rate ($\leq 2°$) [8], the IMUs are more complex to calibrate and more expensive, making the potentiometers better to replicate the device at a low cost while maintaining a good accuracy level. In addition, this prototype does not include any force measurements. Another similar device uses the ROM for a motion capture device [9]. Since the objective of this prototype was motion capturing, there are no ROM measurements, making it difficult to evaluate if its performance would allow a better assessment for the rehabilitation process.

As shown in Table 2, the accuracy corresponding to the force measurements is globally barely over 50%. This can be improved by ensuring the FSRs have a correct connection, since faulty connections were detected on them during testing. Another issue was that the available sensors were not as accurate as expected. Therefore, if replaced, the device's accuracy for grip strength measurement will improve exponentially.

Table 2. Data comparison obtained from 10 subjects using the Hand Assessment Device vs the Grip Force Transducer

Finger-pulp pinch (thumb+index)		
HAD [N]	Grip Force Transducer [N]	Accuracy
17.31	33.11	52.74%

The data obtained in Table 3 correspond to three hand measurements that provide a global view of a patient's hand size. This was done in order to determine whether the HAD has enough versatility to be used on any adult patient, regardless of their hand size. The device evaluation was performed using a total of 10 subjects, 5 men and 5 women. In this case, the male subjects largest hand length was 21 cm, while for the female subjects was 18.40 cm. Comparing these values with the average hand size for males (19.30 cm) and females (17.27 cm), it can be ensured that the HAD has enough adaptability to be used in any adult patient [13].

Table 3. Subjects' hand size

Subject	Hand length[b)] [cm]	Hand width[b)] [cm]	Thumb length[c)] [cm]
1l	18	8.5	11.4
2	19.3	8.2	11
3	18.4	7.5	11.7
4	17	8	11.5
5	16.8	8.0	11
6	21	10.4	16.5
7	18.4	8.9	10.3
8	16.8	7.6	11.6
9	17.5	7.5	12
10	18	8.7	14.3

a) Hand length: measured from the tip of the longest finger to the crease under the palm.
b) Hand width: measured below the knuckles excluding the thumb.
c) Thumb length: measured from the tip of the thumb to the crease under the palm.

4 Conclusions

Knowing the range of motion and pressure applied by the hand is fundamental in order to prescribe an ideal rehabilitation process, thus allowing patients the best opportunity to recover their functionality. Therefore, the HAD is an innovative tool that will allow physiotherapists to perform detailed, accurate and quantifiable assessments on patients that are in need of hand rehabilitation, providing the best outcome possible.

The prototype fabricated presented an average accuracy of 81.62% in ROM measurement and 52.47% in grip strength measurement. These results will be improved by replacing the selected sensors and modifying the design vulnerabilities that were detected during the testing process. Even though these limitations were detected, the HAD is an excellent start for a device that can measure both instantaneously. Moreover, the HAD's adjustability has been ensured thanks to the comparison made with the average hand size for males and females, ensuring that it can be used to assess any adult hand.

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