






# Hardware-Software Data Acquisition System for Measuring the Grip Strength in Children

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**Abstract**— The objective of this project was to design an accessible hardware-software system for measuring and recording grip strength in children. Two graphical user interfaces and two specific application data acquisition boards were designed to process data from four force sensors. One of the graphical interfaces was implemented with LabVIEW on a personal computer, and the other with App Inventor for smart mobile devices, such as phones and tablets, running the Android operating system. The data acquisition boards were designed and implemented using one of them a PIC18F2550 microcontroller, and the other one with a NODEMCU ESP32s development board. The boards can communicate wired or wirelessly with the interfaces and can be powered through their USB ports using a 5V charger or a 5-volt power bank. The measured data are recorded locally on the interface devices.

**Link to graphical and video abstracts, and to code:**  
<https://latamt.ieeer9.org/index.php/transactions/article/view/10161>

**Index Terms**— App Inventor, data acquisition system, grip strength, hardware-software interface, LabVIEW

## I. INTRODUCTION

THE main objective of this project was to design an accessible hardware-software system for measuring and recording grip strength in children. That allows pediatricians to measure a patient's grip strength and assist in the assessment of a diagnosis related to neuromotor problems. In Mexico, there are no specific tools for diagnosing neuromuscular diseases that could provide pediatricians with a reference point. Most current diagnostic methods are either appraisal, or only for physiotherapy or invasive use [1]. The Jamar dynamometer is used as a reference strength measurement instrument in physiotherapy follow-ups or in adults with mobility problems due to injury or illness [2].

Until the age of 12, grip strength varies little in boys and girls, and after that, the increase in strength changes due to physiological growth [3]. Multiple PCR molecular tests for the diagnosis of Duchenne muscular dystrophy have been used in Mexico, but they are very expensive and the waiting time for

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results is long, so it is necessary to have a tool that assists the physician in his diagnosis [4].

In this context, the hardware-software system presented in this project is a useful, portable, and low-cost tool intended to address a need, as grip strength can be used as a reference for the diagnosis of neuromotor disorders.

Devices and systems designed to measure grip strength have been reported in the scientific literature, such as the one developed by A. Alzayed et al., who created a system to automatically and objectively measure a patient's grip strength on an object while traction is applied to slide it from their hands [5]. This instrument measures and records both the grip strength and the minimum traction force required to slide the object from the patient's hands. The system is used in the rehabilitation of individuals who have suffered a stroke.

S. M. Biju et al. reported a glove incorporating nine resistive force sensors (FSRs) and five flexible sensors to measure hand grip strength. They used an algorithm that classifies the type of force applied as either a pencil grip when using finger grips or an object grip when the palm is involved [6]. Data acquisition was performed using an Arduino Due development board, and the results were recorded in a comma-separated values (CSV) file.

In [7], FSR sensors were used in the implementation of a force myographic system to detect movement intention, with application to hand rehabilitation through control of a soft robotic glove. The acquisition of the force myographic signals was performed with an Arduino Mega 2560 development board, on which a neural learning algorithm and control of the robotic glove were also implemented.

In [8] the authors presented a dynamometer based on the ZNHM-III force-sensing bridge, using an STM32 microcontroller for data acquisition and processing. The captured data is sent via Bluetooth communication to a cell phone, which transfers it to a cloud database so that it can be accessed remotely from a computer or application.

D. Pani et al. developed a device for local or remote monitoring of hand rehabilitation sessions in rheumatic patients [9]. They employed different types of sensors to measure various parameters during each session. These included flexiforce A201 force sensors to measure grip strength, pinch strength, thumb opposition strength, and torsional strength; an LX-PA-15 draw-wire sensor to capture hand opening and closing; a Vishay 534 rotary potentiometer to measure dial rotation; a touchpad to measure finger tapping; and an NTC temperature sensor to measure finger temperature. Data transmission is achieved via Bluetooth for

real-time monitoring and via Global System for Mobile Communications (GSM)/General Packet Radio Service (GPRS) for delayed data transmission.

In [10], a grip strength measurement system was presented consisting of a glove with eight FSR sensors, two MCP3208 analog-to-digital converters (ADCs), and an ATmega328P microcontroller. The microcontroller acquires the signals from the ADCs and transmits the data via Bluetooth to a PC or tablet. The data is then filtered and processed using MATLAB software. The system was designed to measure the force exerted by workers with their hands during their tasks.

E. Duarte-Rabelo and E. Morales-Sánchez presented a paper describing the construction of a wireless, portable device that measures hand grip strength by sending a sound feedback whose frequency increases with the applied force. Five piezoresistive force sensors were placed on a glove, and the measured data is transmitted via Bluetooth to a computer or tablet [11].

In [12], a glove for measuring finger grip strength in a tripod setup was presented. Data acquisition was performed using an Arduino UNO board with FSR resistive sensors. The measured data were transmitted to a computer and saved as a CSV file. Using Python libraries, the data was visualized on the computer.

L.H. Camargo, O. A. Pinzón, and D.F. Flórez developed an electronic device to measure the force exerted by the five distal phalanges of a hand [13]. Their device uses force sensors (FSRs) and a graphical interface that displays the measured forces. The device was implemented with a PIC18F4620 microcontroller, a graphic liquid crystal display (GLCD), a Bluetooth communication module, a capacitive keypad, and an SD card for data storage. The Bluetooth module is used to transmit the measured values to a PC.

In [14] a first version of the hardware-software system presented in this project was used to measure grip strength in primary school children from the city of Matehuala, in the state of San Luis Potosí, Mexico. The children did not present any neuromotor or neurological problems. Their results were compared with those of children who attended the neuropediatric department of the Dr. Ignacio Morones Prieto Central Hospital in San Luis Potosí for consultations with neuromotor or neurological problems.

In the hardware-software system presented in this project, a graphical interface for computers was designed, implemented with LabVIEW. This improves the functionality of the previous prototype by allowing the monitoring and visualization of the force applied by four fingers. This is unlike the previous prototype, which measures the average force applied by three fingers without displaying the individual forces of each one. In addition, this work includes an application for mobile devices with the Android operating system, with which monitoring can be performed through a graphical interface on these devices. The measured data are recorded in a database and can be consulted together with the historical record. In addition, two low-cost data acquisition cards were designed, one based on the PIC18F2550 microcontroller and the other based on the NODEMCU

ESP32S development board.

## II. METHODOLOGY

### A. Design of Two Data Acquisition Cards

In order to develop an ourself implemented instrument for measuring grip strength, the measurement system shown in Fig. 1 was designed. It consists of the following elements: a force sensor array, a data acquisition and transmission card, a graphical computer interface, and a graphical interface on a smart mobile device. The input to the system consists of the grip force applied by the index, middle, ring, and pinky fingers of a child's human hand.

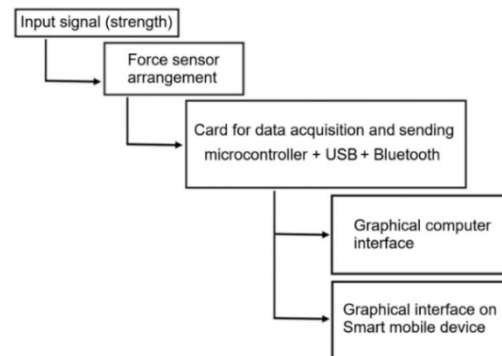


Fig. 1. Elements that make up the grip strength measurement system.

The force sensor array consists of four FSR-402 resistive force sensors, like the one shown in Fig. 2a, mounted on a mannequin hand as shown in Fig. 2b. The sensor is covered by a latex glove that protects it and allows the device to be cleaned after use or to change the latex glove. The assembly consisting of the force sensor array and the mannequin hand on which they are placed has been referred to as the "sensing hand." The sensing hand has five connection lines, one of which connects one terminal of each force sensor to the positive voltage supply of the data acquisition card, and the other connects the free terminals of each sensor to four analog input terminals of the same data acquisition card.

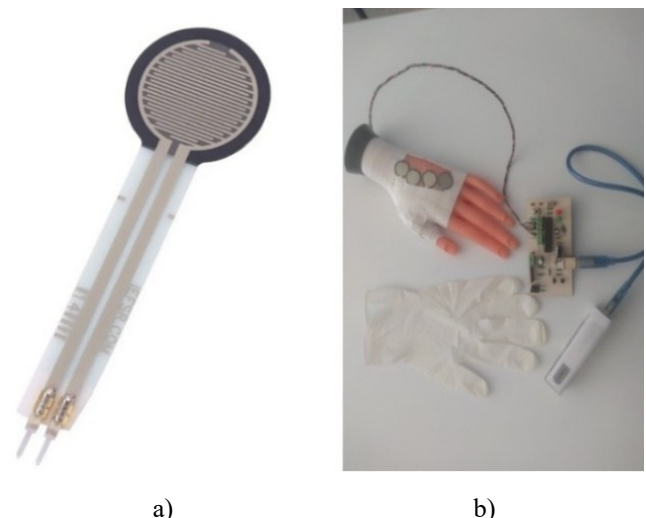


Fig. 2. a) FSR-402 sensor and b) experimental array of four sensors mounted on a hand mannequin.

The FSR-402 resistive force sensor is optimized for use in human touch control in electronic devices and operates within a range of 0.02 kgf to 10 kgf [15]. The sensor's characteristic curve is shown in Fig. 3.

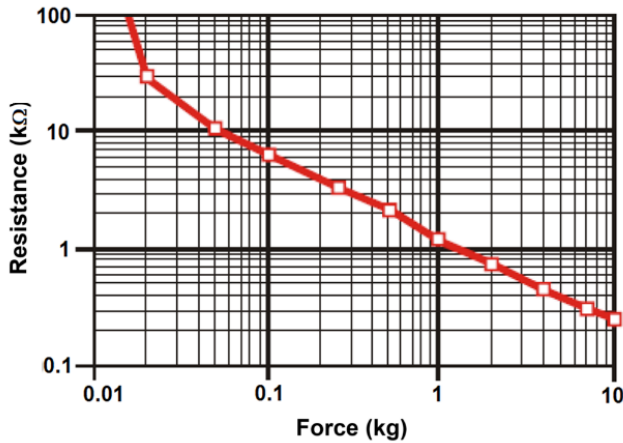


Fig. 3. Response characteristic of the FSR-402 sensor. The log-log plot illustrates the nonlinear inverse dependence between Force (kg) and Resistance (kΩ).

In order to measure the signals produced by the sensors, it is necessary to have a data acquisition device, which captures the values produced and transmits them to the information

processing and visualization system resident in a computer or a mobile device. There are studies that report the use of PIC18F4550 microcontrollers for this type of task [16]-[18]. Other authors use data acquisition devices based on the NODE MCU ESP32 development board, because it incorporates a USB communication module, a Bluetooth communication module and also a module for WiFi communication [19]-[21].

Two data acquisition cards were designed. The first is based on the PIC18F2550 microcontroller, its schematic diagram shown in Fig. 4. The data acquisition card has an input port to which the wires from the sensing hand are connected. Voltage dividers are formed by the arrangement of the four resistors of the FSR-402 sensors, denoted as *SN0*, *SN1*, *SN2*, and *SN3*, and the resistors *R0*, *R1*, *R2*, and *R3*, each of 270 Ω, located on the card board.

An HC-06 Bluetooth communications module is used, which receives the data transmitted by the microcontroller on its Rx terminal. In turn, the HC-06 module retransmits the measurement data using the Bluetooth 2.0 communications protocol. The PIC18F2550 microcontroller operates at 5V and uses 5V TTL logic levels for its digital inputs and outputs, as well as its serial port, and the HC-06 Bluetooth module operates at 3.3V and uses 3.3V TTL logic levels for its serial port inputs and outputs.

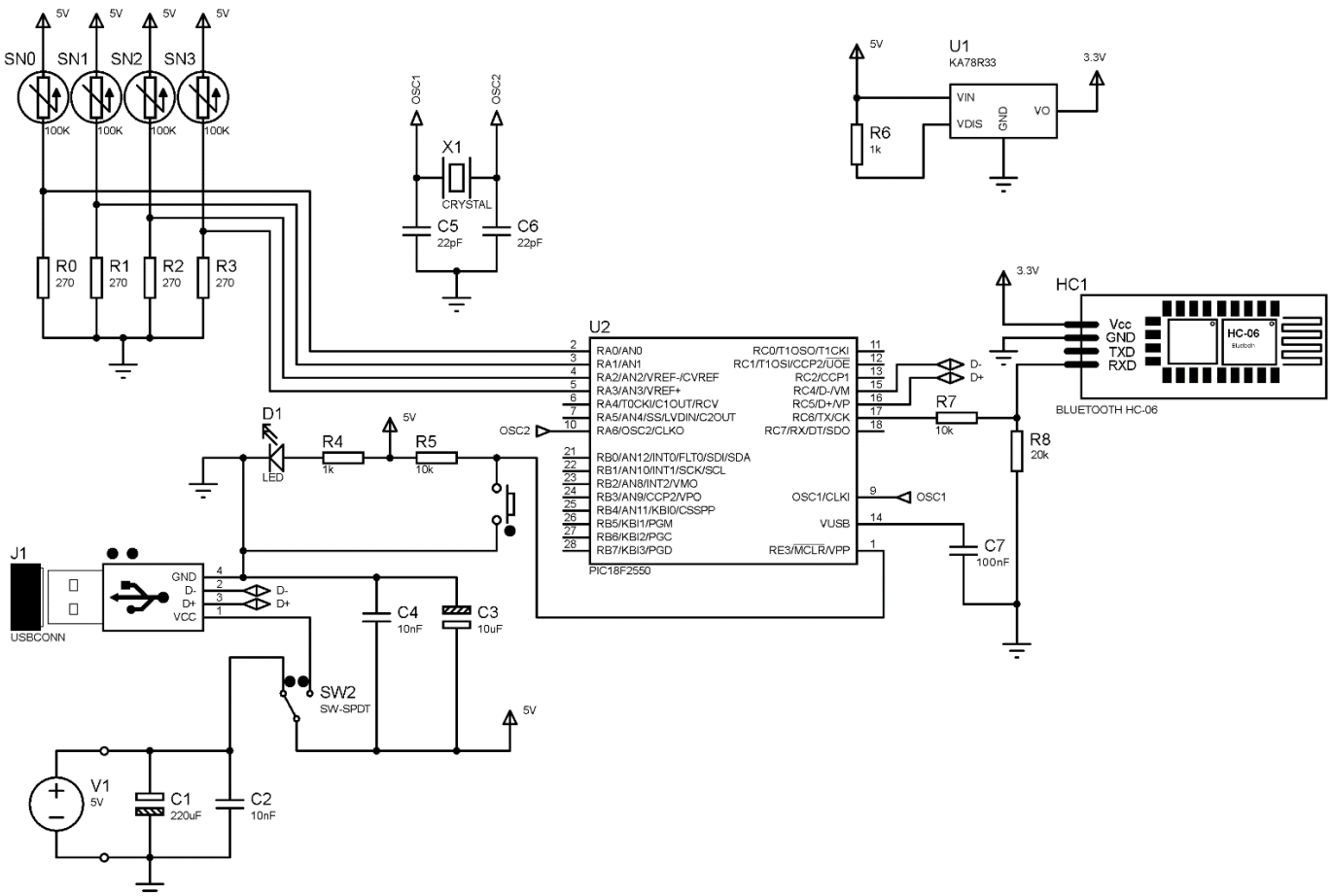


Fig. 4. Data acquisition card circuit based on the PIC18F2550 microcontroller.

To couple the 5V TTL logic voltage levels of the microcontroller's Tx output terminal with the 3.3V TTL voltage levels of the Bluetooth module's Rx input terminal, a voltage divider circuit with resistors R7 of 10 k $\Omega$  and R8 of 20 k $\Omega$  was used, taking the output voltage across the terminals of resistor R8. The microcontroller communicates with the HC-06 module at a rate of 9600 baud. The HC-06 Bluetooth module communicates with an application residing on a personal computer or a smart mobile device.

A graphical interface has been designed for each application so that the system user can view the measurement results of the forces applied to the FSR-402 sensors. The data acquisition board has two ports for powering its circuits, designated Port A and Port B. Port A can be powered by a regulated 5V DC voltage source, and Port B has a USB connector through which it can be connected to devices such as backup batteries, mobile device chargers, or a computer's USB port, which provide the board with 5V DC voltage.

The PIC18F2550 microcontroller provides the board with the ability to communicate with other devices using the USB protocol. The card can communicate with a personal computer via port B using the USB protocol, or it can communicate with the HC-06 module using the Bluetooth protocol. In both cases, the card can be identified by the LabVIEW application as a device connected to a virtual serial port.

The program residing in the microcontroller was written in C language and is shown in Listing I. The analog-to-digital converter module of the PIC18F2550 microcontroller with 10-bit resolution is used to acquire data from the four voltage dividers of the FSR-402 sensors of the sensing hand, through analog input channels 0, 1, 2, and 3. The data is read in four unsigned 16-bit variables: q0, q1, q2, and q3 and is sent through the USB and serial ports to the Bluetooth module in a formatted string that begins with a \* character, separates data with a | character, and ends the string with a line feed \n.

A data acquisition board was also designed based on the NODEMCU ESP32S development board, as shown in Fig. 5.

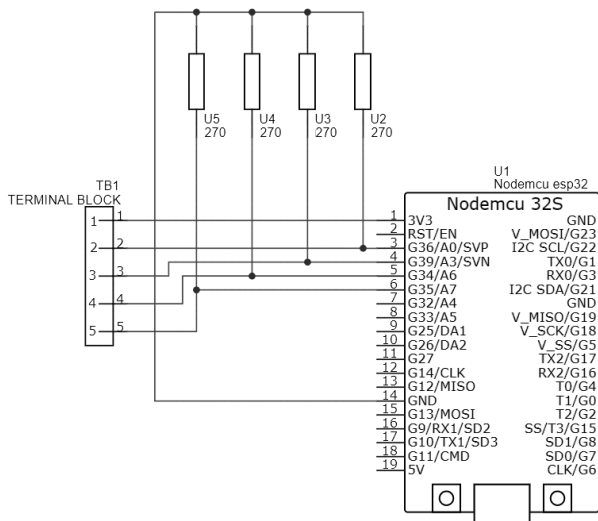


Fig. 5. Circuit of the data acquisition card using the NODEMCU ESP32S card.

The development board was mounted on a printed circuit board to include the conditioning circuitry. The development board has integrated circuits that provide communication using the USB and Bluetooth 4.2 protocols. The program residing on the NODEMCU ESP32S board was written in the Arduino IDE and is shown in Listing II.

```

LIST I
DATA ACQUISITION CARD PROGRAM WITH PIC18F2550
//
// Program that senses four FSR-402 sensors and transmits their values
// via USB and Bluetooth communication.
// Program implemented in the PIC18F2550 microcontroller
//
#include <18F2550.h> // microcontroller definition library
#fuses HSPLL, NOWDT, NOPROTECT, NOLVP, NODEBUG,
USBDIV, PLL5, CPUDIV1, VREGEN // microcontroller configuration
#device adc=10 // Selecting the ADC resolution
#use delay(clock=4800000) // oscillator settings
#use rs232(baud=9600, xmit=pin_C6, rcv=pin_C7, bits=8) //Config
USART
#include <usb_cdc.h> // cdc class library
#include <usb_desc_cdc.h>
#include <math.h> // mathematical library
void main() {
    int16 q,q0,q1,q2,q3; // variables for sensor values
    q1=0;
    // start USB port and check connection
    usb_cdc_init();
    usb_init();
    while (!usb_cdc_connected()) {}
    usb_task();
    while (!usb_enumerated()) {}
    // ADC Converter Configuration
    setup_adc_ports(ALL_ANALOG);
    setup_adc(ADC_CLOCK_INTERNAL);
    set_adc_channel(0);
    // Capturing the values from the four sensors
    do {
        delay_ms(10);
        set_adc_channel(0);
        delay_us(80);
        q = read_adc();
        delay_us(500);
        q0 = q*1+1000; // add 1000 to have four decimal digits
        set_adc_channel(1);
        delay_us(80);
        q = read_adc();
        delay_us(500);
        q1 = q*1+1000; // add 1000 to have four decimal digits
        set_adc_channel(2);
        delay_us(80);
        q = read_adc();
        delay_us(500);
        q2 = q*1+1000; // add 1000 to have four decimal digits
        set_adc_channel(3);
        delay_us(80);
        q = read_adc();
        delay_us(500);
        q3 = q*1+1000; // add 1000 to have four decimal digits
        // a string with the values of the four sensors is sent
        // the chain has a fixed length
        printf("%Lu%Lu%Lu%Lu\n",q0,q1,q2,q3);
        printf(usb_cdc_putc, "%Lu%Lu%Lu%Lu\n",q0,q1, q2,q3);
    } while (TRUE);
}

```

The samples captured by the data acquisition boards, corresponding to the forces applied by the pressure of a user's fingers on the force sensors of the sensing hand, are sent without filtering or processing to a personal computer or a smart mobile device for filtering, processing, and display in a graphical interface, so that the user is aware of these measured force values.

LIST II: DATA ACQUISITION CARD PROGRAM WITH NODEMCU ESP32S

```
// Program that senses four FSR-402 sensors and transmits
// them via USB and Bluetooth communication.
// Data acquisition card based on the NODEMCU ESP32s
//
#include "BluetoothSerial.h"
#if !defined(CONFIG_BT_ENABLED) ||
!defined(CONFIG_BLUEDROID_ENABLED)
#error Bluetooth is not enabled! Please run `make menuconfig` to and
enable it
#endif
BluetoothSerial SerialBT;
Int w, x, y, z; // Variables representing measurements from four sensors
Int sensorw = 36; // The pin called 36 is assigned the name sensorw
Int sensorx = 39; // The pin called 39 is assigned the name sensorx
Int sensory = 34; // The pin called 34 is assigned the name sensory
Int sensorz = 35; // The pin called 35 is assigned the name sensorz
void setup(){
Serial.begin(115200); // Transmission speed 115200 bps
SerialBT.begin("ESP32_Mano"); // Name Bluetooth module
pinMode(sensorw, INPUT);
pinMode(sensorx, INPUT);
pinMode(sensory, INPUT);
pinMode(sensorz, INPUT);
AnalogReadResolution(10); // The ADC resolution is set to 10 bits.
}
void loop() {
w = analogRead(sensorw)+1000; // Read analog input w on pin 36
x = analogRead(sensorx)+1000; // Read analog input x on pin 39
y = analogRead(sensory)+1000; // Read analog input y on pin 34
z = analogRead(sensorz)+1000; // Read analog input z on pin 35
Serial.print("*"); // sends an identifier via serial port before
// the first number
Serial.print("|"); // sends a "|" character as a separator
Serial.print(w, DEC); // sends the value of sensor W
Serial.print("|"); // sends a "|" character as a separator
Serial.print(x, DEC); // sends the value of sensor X
Serial.print("|"); // sends a "|" character as a separator
Serial.print(y, DEC); // sends the value of sensor Y
Serial.print("|"); // sends a "|" character as a separator
Serial.print(z, DEC); // sends the value of sensor Z
Serial.println("|"); // sends a "|" character as a separator
SerialBT.print("*"); // sends an identifier before
// the first number via Bluetooth port
SerialBT.print("|"); // sends a "|" character as a separator
SerialBT.print(w, DEC); // sends the value of sensor W
SerialBT.print("|"); // sends a "|" character as a separator
SerialBT.print(x, DEC); // sends the value of sensor X
SerialBT.print("|"); // sends a "|" character as a separator
SerialBT.print(y, DEC); // sends the value of sensor Y
SerialBT.print("|"); // sends a "|" character as a separator
SerialBT.print(z, DEC); // sends the value of sensor Z
SerialBT.println("|"); // sends a "|" character as a separator
delay(30); // wait 30ms for the next reading
}
}
```

### B. Design of Two Graphical Interfaces

To display the values captured by the data acquisition cards, two graphical interfaces were designed: one for a personal

computer and one for mobile devices. The graphical interface for the personal computer was designed and implemented using LabVIEW. The application's front panel is shown in Fig. 6.

This front panel displays a graph that represents the force applied by the user when pressing the sensors on the sensing hand. Vertical bar indicators are also included to display the result in ascending order, providing the user with visual feedback. Numerical indicators also include: the magnitude of the instantaneous force applied to each sensor, the maximum force applied by each finger, the average force applied by the four fingers, the average of the maximum force applied by the four fingers, and the maximum sum of the instantaneous force values of the four fingers, expressed in kilograms-force and newtons.



Fig. 6. Front panel of the graphical interface developed in LabVIEW for measuring the grip force of four fingers (F1–index, F2–middle, F3–ring, and F4–little).

There is also a virtual button that allows you to clear the graphical and numerical results and prepare the system for another measurement. Must be considered that LabVIEW is proprietary software; therefore, appropriate licensing is required to develop, execute, and replicate the proposed system.

An application was also designed to provide a graphical user interface for smartphones running the Android operating system. The application was designed using the App Inventor platform [22]. Fig. 7 shows the screen of this graphical interface. The application screen displays two graph areas, one Cartesian and the other bar graphs, which represent the instantaneous forces applied to each of the four sensors of the sensing hand.

There are three virtual buttons: one to link the application to the Bluetooth communications module of the data acquisition card, one to start or pause data capture, and a virtual button that performs two functions: displaying data statistics or returning to data capture.

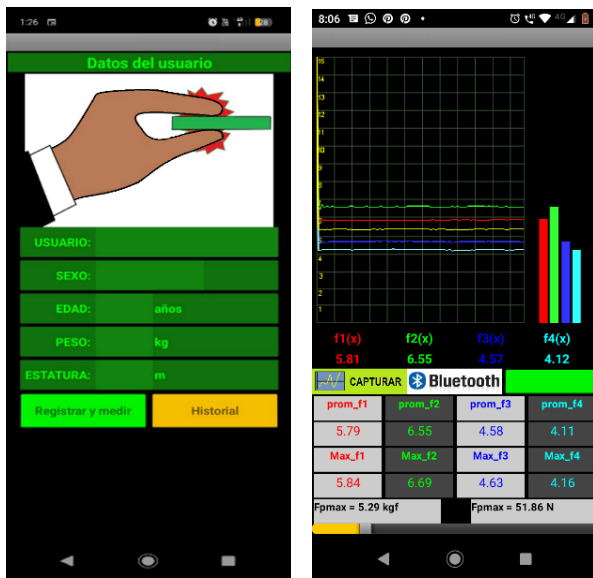


Fig. 7. Graphical interface of the application on a mobile phone. a) User data registration. b) Measuring grip strength.

While graphing the grip strength data, the coordinates of one or more data points of interest can be marked on the Cartesian graph by tapping the screen. The organization diagram of the application program is shown in Fig. 8.

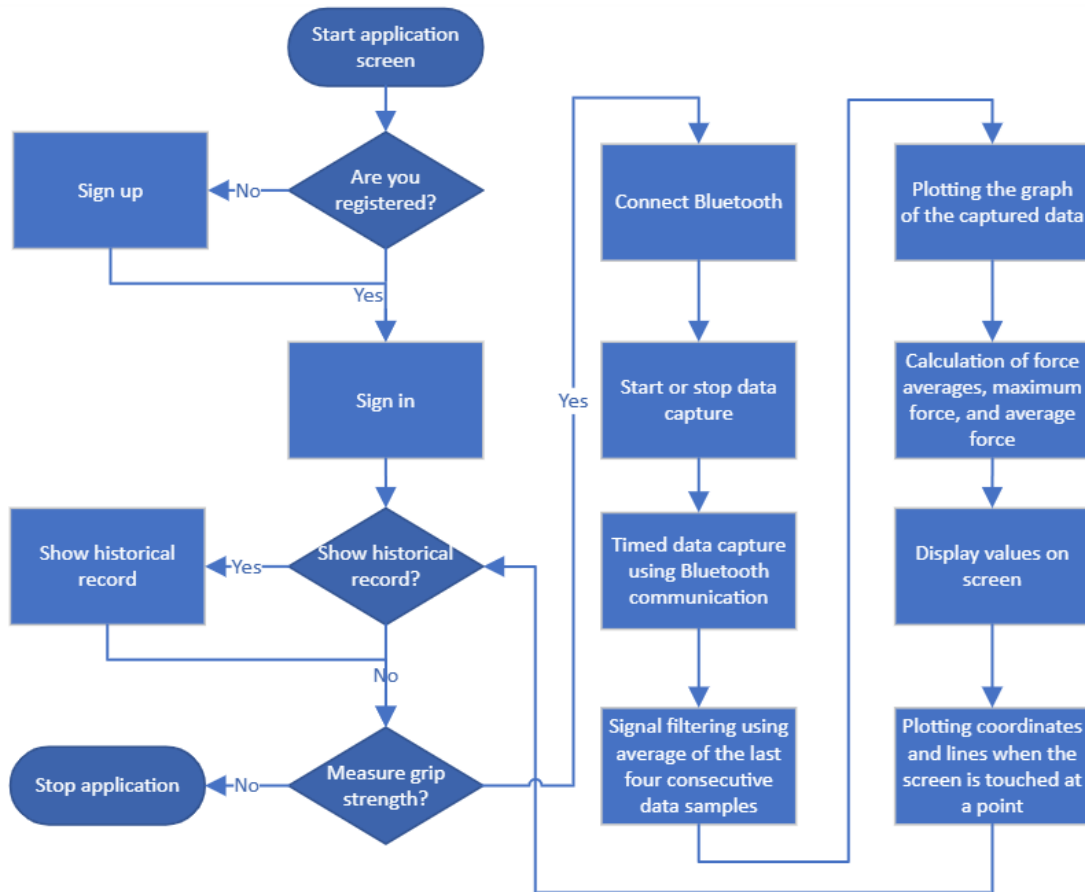


Fig. 8. Organization of the application program developed in MIT App Inventor. The block diagram illustrates the main algorithm of the mobile application used as an interface to display the grip-force measurements of four fingers of the hand.

In addition, this work includes four-sample windowed average digital filters applied to the signals delivered by the sensors once they are digitized. This filtering was included in the virtual instrument in LabVIEW and in the application developed with App Inventor for the mobile device.

C. Determination of the Measured Force

To determine the applied force  $F_a$  on the  $i$ th  $SN_i$  FSR-402 sensor ( $i=0,1,2,3$ ), the circuit in Fig. 9 was used. The sensor was placed on a digital scale and was applied force to the sensor surface, which was transmitted to the scale. The scale reading indicated the magnitude of the applied force  $F_a$  on the sensor and on it, expressed in kilograms force (kgf).

When force is applied to the sensor, a voltage  $V_i$  is produced in the voltage divider it forms with the  $270 \Omega$  resistor. This voltage is applied as the input voltage to one of the channels of the analog-to-digital converter module of the data acquisition card, which converts it into an integer  $NCAD_i$  that is transmitted to the personal computer or mobile device.

For each of the sensors, the relationship between the applied force  $F_a$  and the  $NCAD$  number is determined, so that later, using this number, the force applied to the sensor can be determined. In [11], it is indicated that in FSR-402 sensors, the relationship between the applied force  $F_a$  and the voltage  $V_i$  is quadratic, and thus a quadratic relationship between  $F_a$  and  $NCAD$  is also implied.

### III. RESULTS

For each sensor, a calibration was carried out by placing weights on it, being supported on a digital scale, so that the weight of the reference weight and the value marked by the scale were compared, which should be the same. Further samples were then taken by pressing on the surface of the sensor, while it was supported on the scale, and pairs of data were recorded, corresponding to the applied force and the  $NCAD$  number recorded by the analog-to-digital converter of the microcontroller. The force versus  $NCAD$  number graph shown in Fig. 10 was performed with one sensor test and is similar but not the same for each of the  $SN_0$ ,  $SN_1$ ,  $SN_2$  and  $SN_3$  sensors.

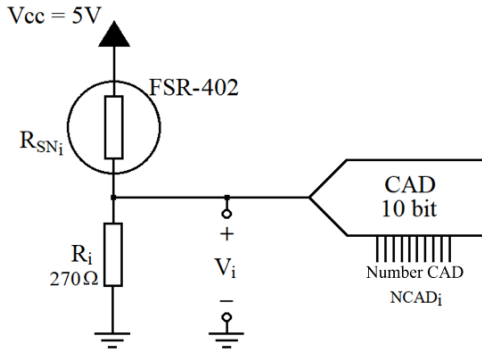


Fig. 9. Force measurement circuit using the FSR-402 sensor.  $R_{SN_i}$  denotes the nonlinear resistance of the sensor. The CAD is the converter on the data acquisition board that represents the input analog voltage as a digital number  $NCAD_i$ .

The character  $\times$  is used to show the values of applied force measured by the digital scale and the continuous line shows the graph of applied force  $F_a$  predicted by an equation obtained by regression analysis. In this work was determined that the relationship between the applied force  $F_a$  and the  $NCAD$  number is cubic polynomial, in the general form shown in (1).

$$F_a = K_3 NCAD^3 + K_2 NCAD^2 + K_1 NCAD + K_0 \quad (1)$$

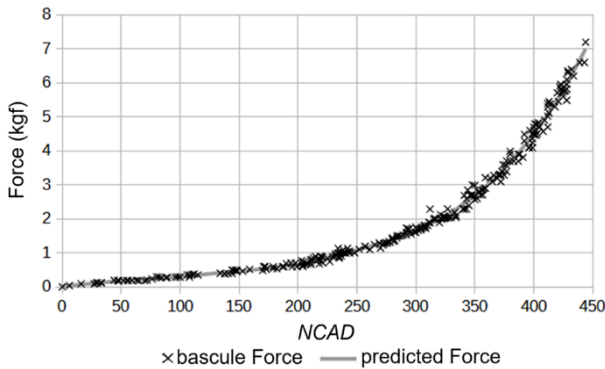


Fig. 10. Applied force as a function of the  $NCAD$  number of the force sensor.

Improved modeling is also achieved by dividing the range of  $NCAD$  numbers into two intervals and using a cubic

equation for each interval. The intervals for  $NCAD$  are:  $0 \leq NCAD \leq 195$  and  $196 \leq NCAD \leq 1023$ . Furthermore, generally, the pair of equations used for one sensor does not have the same coefficients as for another sensor, so each sensor was calibrated individually to determine the  $K_3$ ,  $K_2$ ,  $K_1$  and  $K_0$  coefficients in each of its intervals.

Table I shows the coefficients used in the cubic equations for each sensor, and Table II shows the determination coefficients obtained for each equation in its corresponding  $NCAD$  interval. Table III, Table IV y Table V shows Standard Deviation, Mean Absolute Error MAE and Mean Absolute Percentage Error MAPE, respectively.

The  $R^2$  determination coefficients shown in Table II are greater than 0.89 in the low range and greater than 0.98 in the high range, indicating that the cubic polynomial fit explains between 89% and 99% of the data variability. This validates the proposed cubic polynomial relationship between applied force and  $NCAD$  for each sensor, especially when  $195 < NCAD$ , which is when the  $R^2$  determination coefficient is closest to 1.

The standard deviation ( $\sigma$ ) and mean absolute error (MAE) (Table III and Table IV) show values consistent with FSR sensors, which exhibit greater dispersion at low forces. The mean percentage error MAPE, shown in Table V, is less than or equal to 14% in the low range, and is less than 6.24%. The lower MAPE in the high range suggests that the instrument is more accurate for greater forces, where greater precision is typically required to assess grip strength.

TABLE I  
COEFFICIENTS OF THE SENSORS EQUATIONS RELATING THE APPLIED FORCE TO THE DIGITAL OUTPUT  $NCAD$  AS EXPRESSED IN (1) FOR THE TWO CALIBRATION INTERVALS

$NCAD$	Sensor	$K_3$	$K_2$	$K_1$	$K_0$
[0,195]	$SN_0$	$4.08 \times 10^{-5}$	$-9.07 \times 10^{-3}$	3.37	18.48
[0,195]	$SN_1$	$4.87 \times 10^{-5}$	$-7.11 \times 10^{-3}$	2.43	5.42
[0,195]	$SN_2$	$4.12 \times 10^{-5}$	$-5.17 \times 10^{-3}$	2.28	7.79
[0,195]	$SN_3$	$8.77 \times 10^{-5}$	$-3.76 \times 10^{-2}$	8.54	17.56
[195,1023]	$SN_0$	$4.29 \times 10^{-4}$	$-2.94 \times 10^{-1}$	75.67	-6148.67
[195,1023]	$SN_1$	$1.74 \times 10^{-4}$	$-72.4 \times 10^{-3}$	17.12	-1409.2
[195,1023]	$SN_2$	$1.83 \times 10^{-4}$	$-8.09 \times 10^{-2}$	19.82	-1696.3
[195,1023]	$SN_3$	$2.40 \times 10^{-4}$	$-1.05 \times 10^{-1}$	19.91	-640.03

TABLE II  
DETERMINATION COEFFICIENTS  $R^2$  OF THE SENSORS CALIBRATION MODELS USING (1) FOR THE TWO CALIBRATION INTERVALS

Sensor	$R^2$	
	$NCAD \in [0,195]$	$NCAD \in [196,1023]$
$SN_0$	0.96526	0.99330
$SN_1$	0.95178	0.98994
$SN_2$	0.95090	0.98710
$SN_3$	0.89675	0.98407

TABLE III  
STANDARD DEVIATION OF THE APPLIED FORCE VALUES  
ESTIMATED FROM NCAD USING THE MODEL IN (1) FOR THE  
TWO CALIBRATION INTERVALS

Sensor	Standard deviation $\sigma$ NCAD $\in [0,195]$	Standard deviation $\sigma$ NCAD $\in [196,1023]$
$SN_0$	31.60	137.97
$SN_1$	34.25	208.82
$SN_2$	34.243	208.36
$SN_3$	81.62	274.18

TABLE IV  
MEAN ABSOLUTE ERROR MAE OF THE APPLIED FORCE  
ESTIMATED FROM NCAD USING THE MODEL IN (1) FOR THE  
TWO CALIBRATION INTERVALS

Sensor	MAE NCAD $\square [0,195]$	MAE NCAD $\square [196,1023]$
$SN_0$	25.75	99.875
$SN_1$	28.46	153.50
$SN_2$	28.623	154.49
$SN_3$	69.76	212.09

TABLE V  
MEAN ABSOLUTE PERCENTAGE ERROR MAPE OF THE FORCE  
APPLIED ESTIMATED FROM NCAD USING THE MODEL IN (1)  
FOR THE TWO CALIBRATIONS INTERVALS

Sensor	MAPE NCAD $\in [0,195]$	MAPE NCAD $\in [196,1023]$
$SN_0$	7.86%	4.38%
$SN_1$	10.91%	5.28%
$SN_2$	11.13%	5.42%
$SN_3$	13.99%	6.24%

The standard deviation, less than 0.08162 kgf in the NCAD  $< 195$  range, is relatively low, and in the high range where  $195 < NCAD$ , it is less than or equal to 0.27418 kgf. This variation is due to the nonlinearity of the sensors, but it is compensated for by the low MAPE in that range.

The implementations of the data acquisition board using PIC18F4550 and the NODEMCU ESP32S based data acquisition board, as well as the graphical interfaces implemented in LabVIEW and on a smartphone are shown in Fig. 11. The performance of the prototypes designed and implemented in this study was compared and validated with the system implemented with the NI USB-6008 data acquisition card and the acquisition card based on the PIC16F876A microcontroller reported in [14]. The prototypes in this study incorporate more functions, providing individual values for the force measurements exerted by four fingers and the total value of the grip force exerted by them.

The mobile device interface incorporated in this study also presents an advantage in implementation feasibility given the scarcity or obsolescence of computer equipment in healthcare

institutions, as healthcare personnel are more likely to have a smart device. In addition, the software tools used for the design of the data acquisition cards are open source, as is the software used in the mobile device interface.

Other studies on grip force measurement have been reported in the literature, such as the one in [5], which measures the grip force on a tubular object and also the pulling force required to make the object slide from the hands holding it. This system uses load cells to measure the forces involved. The system is useful, but it is not portable and is not inexpensive.

Other force measurement systems, such as the one reported in [6], consist of resistive force sensors and flex sensors placed in a glove. It allows for the measurement of grip and pinch force. The acquired data are saved in a CSV file. A notable feature is that it incorporates machine learning to classify the data type according to force scales and the type of grip involved. The Arduino DUE acquisition board is connected with single-pin wires, making it vulnerable to disconnections.

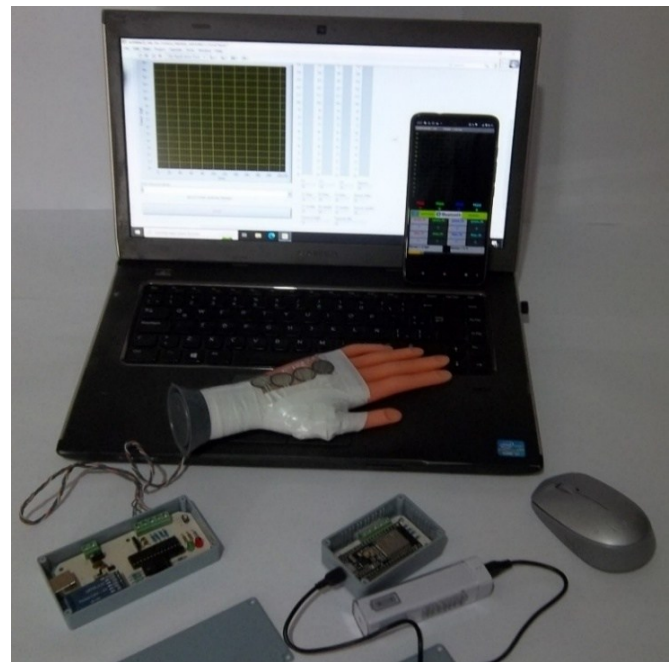


Fig. 11. Implementation of the hardware-software system for grip strength data acquisition, implemented with PIC18F2550, NODEMCU ESP32S and with graphical interfaces in LabVIEW and App Inventor.

In [9], the authors report a force measurement system for rehabilitation sessions with local or remote monitoring. This comprehensive system measures grip, pinch, effort, extension, and temperature, but it is not inexpensive.

Several measurement devices use glove-mounted sensors, such as those reported in [10]–[12]. One measures the pinch force exerted by the index, middle, and thumb fingers [12], while another measures the force exerted by all five fingers [11]. In [13], Flexoforce FSR A201 sensors are used to measure the force exerted by the five fingers, displaying the information on a GLCD screen and on a personal computer with which they have wireless communication, storing the

information on a memory card.

In comparison, this work presents two data acquisition cards, both with wired and wireless communication, measuring the grip force of four fingers of the hand, displaying the information on personal computer and mobile device interfaces and saving the measures in local files to each kind of device. Compared to data acquisition systems such as those found in [11]-[13], the system presented includes digital mean filters with a four-sample window implemented in the programming of the user interfaces and it can display the information on computers or mobile devices such as smartphones and tablets. It allows for storing and retrieving user information, provides visual feedback through bar graphs, and is portable. Compared to systems that use gloves, the system presented here is easier to clean, and the glove size makes it difficult to adjust to the hands of children of different ages. The approximate cost of the system, excluding programming and design, was approximately \$140 USD.

The system presented in this project has limitations, some due to the inherent characteristics of the FSR-402 sensor used. This means that measurement error metrics need to be addressed more thoroughly to improve the sensor's response adjustment curve. Recalibrations will also be required due to wear or replacement of defective sensors. Despite these limitations, it has the potential to implement remote monitoring functions due to the functionality of the NODEMCU ESP32S board and smartphone connectivity.

#### IV. CONCLUSIONS

The objective of design an accessible hardware-software system for measuring and recording grip strength in children was met. Two data acquisition card designs were implemented, including the hand with the sensor array, and two user interfaces: one on a personal computer and another for mobile devices running Android.

The system individually measures the grip strength of four fingers: index, middle, ring, and pinky fingers, as well as the average applied force of the four fingers. The data acquisition cards, one based on the PIC18F2550 microcontroller and the other on the NODEMCU ESP32S development board, are low-cost, and the software used for their design is open and free to use. The application for the graphical interface on mobile devices was also developed on an open and free design platform.

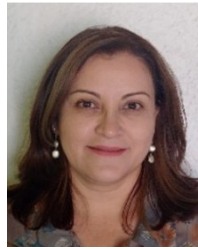
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