System for Monitoring Fingerprint Force

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Abstract. Information management becomes a need when a system is used in a common area in the health services for several physicians and patients, as well as into the portable mobile systems for hand rehabilitation assigned to a home-care therapy. In both cases, tracking is required in seldom clinical dates for physical therapies. Hand injuries due to daily activities or work issues are among the main attended problems; therefore, a system capable of evaluating the physical therapy was created to reduce the physician's time to update the patient follow-up files. This work consists of two main parts, the management subsystem, and the measurement subsystem. It has the option of creating accounts for evaluators, and they can add the patients. The patient information is kept in the database, and the finger's force recordings created during the tests. The digital file of the patients can be consulted later by the assigned evaluator. It has a graphical interface connected to a relational database for storing the information of both evaluators and patients. On the other hand, the measuring system has an interface to visualize the information used to monitor the patient's finger force activity. It has a questionnaire that measures the severity of the patient symptoms in the current session. The patients' created digital file and the data can be consulted later by the evaluator to continue the follow-up session even if a new physician is assigned.

Keywords: Information management, hand rehabilitation, graphical programming, digital file.

1 Introduction

The hands are an essential part of the person's body with which they perform activities such as holding objects and therefore perform various activities in daily life. They are the most used part of the body when performing fine activities in daily activities and therefore tend to be easily injured [1].

The Secretary of Health of Mexico City, Dr. Armando Ahued Ortega, mentions that 26 percent of workplace accidents are in the wrists and hands. In 2016, the Network of the hospital of the Mexico City Government reported that there was a record of 1871 hospital admissions due to wrist and hand trauma [2]. Keeping track of so many public hospital treatments and dates is a time-consuming job of the few highly specialized people because it has not yet been fully migrated to specialized instruments [3].

For this reason, it was proposed to develop an auxiliary system for the evaluator when capturing and recording patients during the rehabilitation processes of both pressure and movement. Portable wireless system proposals that reported the bio instrumentation technology and defined the tracks of the hand's functionality within the processes of evaluation of the result of treatment and rehabilitation therapy are presented in [4, 5]. In the specific case of the fingerprint monitoring, a system based on FlexiForce force sensors with amplifier and low pass filter to send the signal to a NI myRIO® data acquisition board was proposed.

The voltage signal in the FlexiForce sensor is increased when the force is increased. These variations of voltage are normalized in a force scale. The board sends these signals wirelessly to a system similarly made in LabVIEW® as Ortegón does [6]. In this first case, the prototype was designed to be transportable, and the wireless was done with a highly specialized acquisition card. However, the main drawback is that each applicator has to separately apply the paper version of a QuickDash questionnaire into each test session and then concentrate the information manually after completing the registration protocol for both the records and the questionnaires during each rehabilitation therapy [5]. In the second case, the system is over the wrist, and further tests about the usability should be done. Therefore, in this work, the possibility of generating a tool to facilitate the questionnaires' management, evaluation of these results, administration of the signals recorded in the fingerprint evaluation system using LabVIEW® all together with a low-cost acquisition board is proposed.

2 Material and Methods

2.1 Design of the Clamp Device

The clamp devices are used for hand force measurements in clinical, industrial, research, and development; it has ergonomic properties, adjustable, and present flat surfaces where the force sensors are fixed. The mobile section of the device shown in Fig. 1 has two-cylinder sections at the extremes with holes to move the section with cylindrical aluminum bars attached to a fixed section. This section has four finger supports for a firm grip and where the force sensors will be placed. With the use of fixing screws, the appropriate distance between the two sections can be adjusted depending on the hand's size.

2.2 System Architecture

Before starting with the development of the system, various options for the management of information were analyzed, the areas of opportunity in the registration protocol, the rehabilitation doctors' feedback, and the possibility of maintaining the

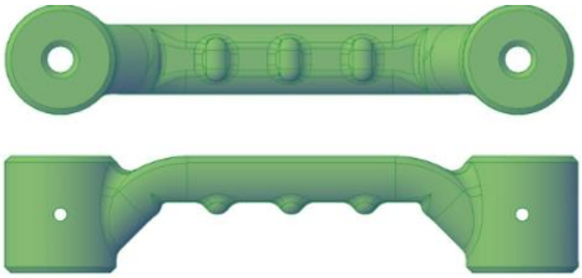

Fig. 1. Front and lateral views of the mobile system.

previous interface's graphic language were analyzed. The software used to program the system with a graphical interface was LabVIEW 2019 [7], a rapid prototype tool used in the industry to design electronics and complete systems where the handling of information acquired by hardware and software processing are integrated.

So that it can be easily used by the evaluator, preserving the possibility of data acquisition, control, analysis, and presentation using transparent methods for the end-user. NI-DAQmx 19.1 was selected for data acquisition management and MySQL for information management. In the electronic instrumentation section, the FlexiForce A201 force sensor was implemented. However, the electronic card design was modified to be in modular printed circuits for each sensor. This version could be used to implement different protocols to be evaluated according to the number of finger pressure measurements required and different measurement configurations proposed by the physicians.

2.3 Force Sensing System

The grab or "clamp" device with the sensors generates the signals from one hand either from the left or right, and the clip device only from one finger depending on the assigned configuration. Therefore, the voltage variations are generated due to the increase or decrease of force. The force measurement into the different tests is sent to the data acquisition board, stored in the patient electronic folder, and displayed in the dashboard. For this purpose, the sensor FlexiForce A201 sensor was implemented with a linear range of 0-55KgF. This sensor uses the variation of its resistance according to the inverse of the pressure exerted on the sensing area.

According to the manufacturer, a preprocessing circuit is required (see Fig. 2). It has been the base for the conditioning of the system. The circuit has been divided into two sections, an amplification circuit, and a low pass filter circuit.

2.4 Amplification Circuit

An inverse amplifier was used for the first stage, which is presented in Fig. 3. The sensors were previously characterized in a range of 0- 55 kg F (100lb) that correspond to the maximum value. It is enough to cover the hand measurements with reported maximum values around 25kgF considering age, BMI, and gender [9, 10, 11].

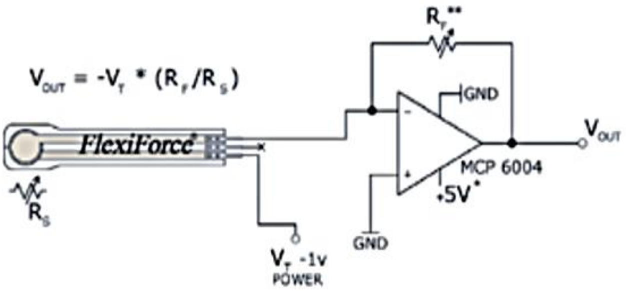

Fig. 2. Recommended circuit by the manufacturer in the datasheet [8].

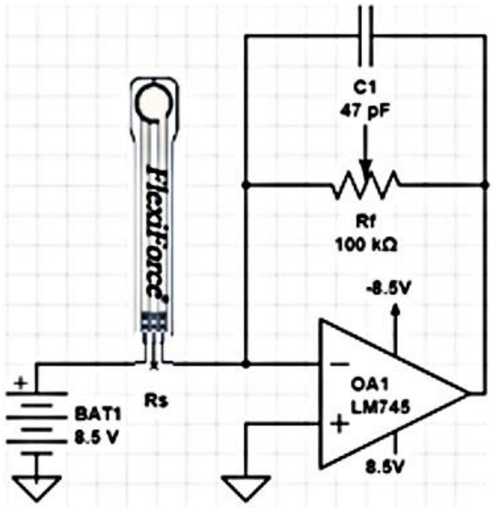

Fig. 3. Fingerprint force system amplification circuit.

The voltage provided is determined by a reference resistance Rf (sensor), so it was used a potentiometer of 100kOhms, for later adjustments and obtain the maximum value of force that can provide the sensor considering the calibration of the sensor with the maximum voltage provided. A ceramic capacitor C1 has been placed parallel to Rf to minimize voltage variations.

The LM741 operational amplifier was used in an inverter amplifier configuration. A constant dual source of ±8.5V to power the LM741 OA1 and the Rs sensor was used, and the maximum value of -7.0V was established in a circuit saturation without force applied. The gain has been calculated considering the variable resistance *Rs* of the FlexiForce sensor. *Rs* presents maximum resistance when it is not pressed, and it is diminished when a force is applied. The value of the gain is obtained from Equation 1. Therefore, the amplifier was implemented to limit the output voltage and not present differences in the sensors' readings:

$$G = -\frac{Rf}{Rs} \ (1).$$

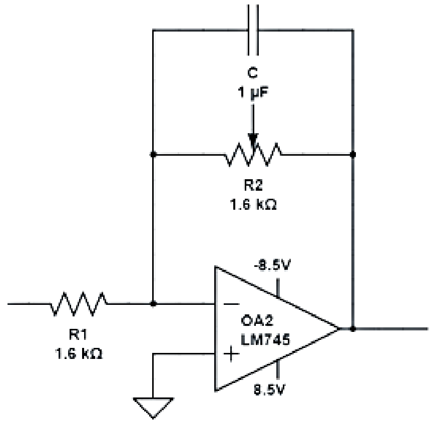

Fig. 4. Schematic of the low pass filter circuit.

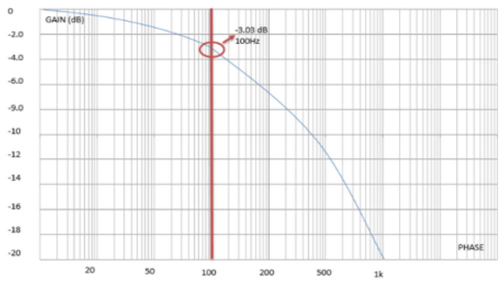

Fig. 5. Cutting the low pass filter at 100Hz from the fingerprint system.

The output voltages *Vout* has been calculated considering the reference resistance Rf. Each sensor has a different performance, so the resistance *Rf* has a potentiometer to adjust the *Vout* when the maximum force is exerted. This calibrated output voltage has been calculated from Equation 2:

$$V_{out} = -V_t * \left(\frac{R_f}{R_s}\right) \text{ (2).}$$

2.5 Low Pass Filter Circuit

The low pass filter was designed with a cut-off frequency of 100 Hz (see Fig. 5) to capture the full signal without interference from the disturbances present when touching the sensors or vibrations presence when the device is in use. The composition of the developed low-pass filter circuit can be seen below (see Fig. 4):

The low pass filter is a first-order inverter with a -3dB attenuation per decade from the 100Hz cut-off frequency. The component values were calculated from Equation 3:

$$f_c = \frac{1}{2\pi R_2 C} \text{ (3).}$$

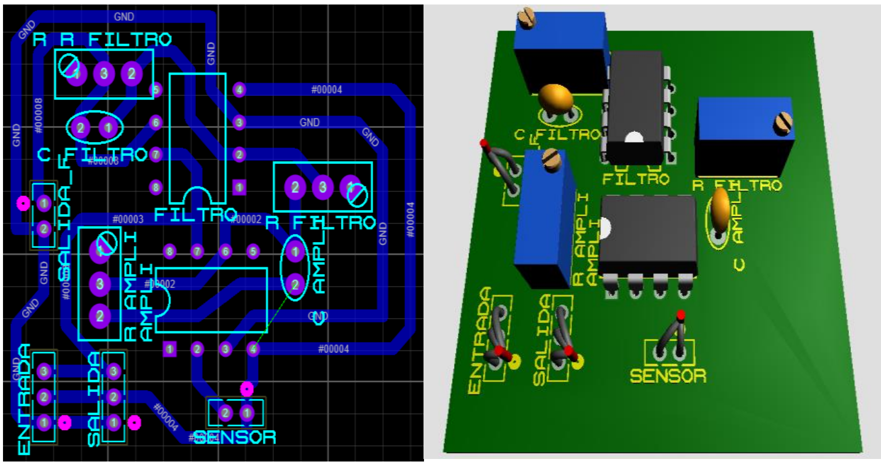

Fig. 6. Modular circuit of the fingerprint system and final circuit in 3D.

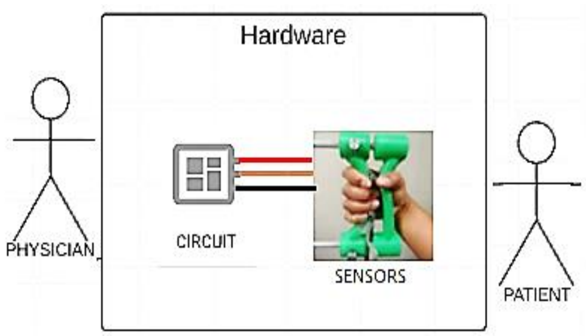

Fig. 7. System architecture for hardware.

The filter response obtained from the calculations was obtained in the implemented filter (see Fig. 4). This filter helps to eliminate electrical noise by movement and vibration.

Fig. 6 shows the circuit of the amplifier and the filter, both implemented in Proteus 8 Professional for a PCB.

Error in the measurement of 0,02% was obtained with respect to the simulation in relation to the implementation. The preliminary performance tests consisted of measuring the voltage variations associated with applying pressure to the sensor with a multi-meter STEREN MUL-600. In data acquisition, a USB-6009 board (NI, USA) [12] was used instead of the NI myRIO® because it is much more economical, light, and has the minimum required features in a therapy room with a pc or a laptop. This hardware architecture is shown below (see Fig. 7).

Finally, six modules were done, five for the grab hand test and the last for a finger's clip test. The sensors were adjusted to a range of 0-44kgF that corresponds to 80% of the maximum value available, and it is enough to cover the measurements in hand.

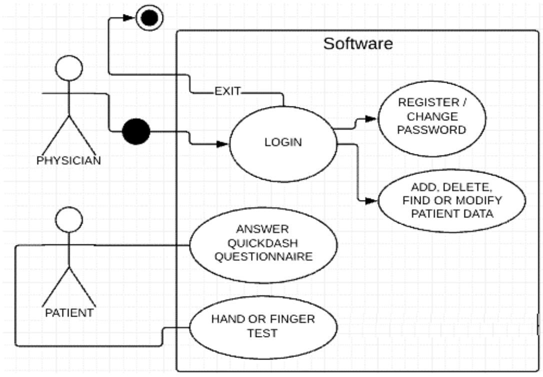

Fig. 8. System architecture for software.

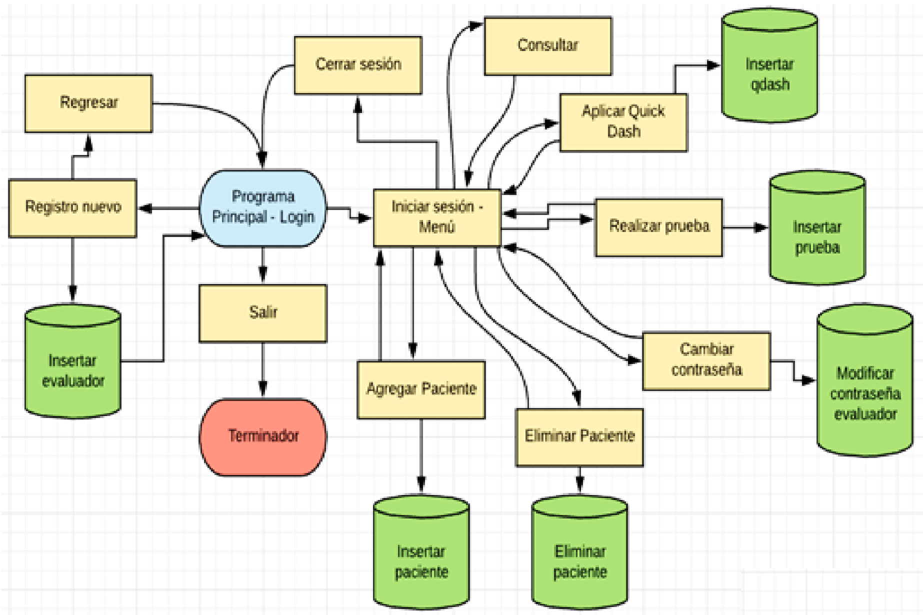

Fig. 9. The flow of processes within the management system.

2.6 Signal Acquisition

The signal pre-conditioning system design for the FlexiForce A201 sensor is retaken, and a modular version was designed based on its datasheet [8]. An upgrade version of the programming language was used considering its capabilities in handling graphical interfaces, handling questionnaires, validating responses, and modules for connecting to databases. Subsequently, the acquisition and processing programming of the obtained signals was implemented.

The software had two profiles: physicians and patients. However, the only direct end-user is the physician, with login or register of account. Once an account is created,

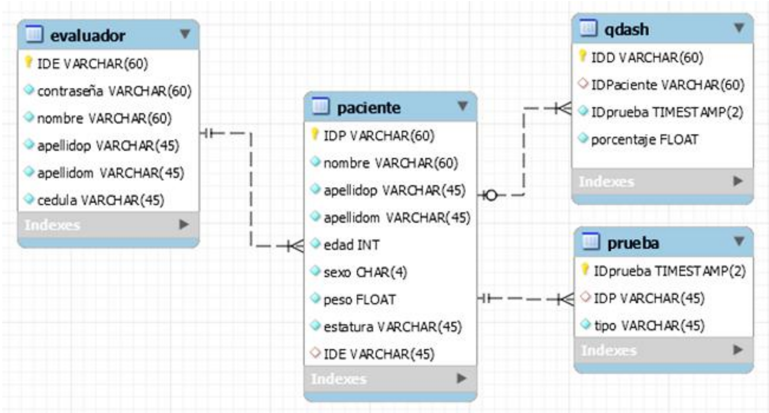

Fig. 10. Database diagram.

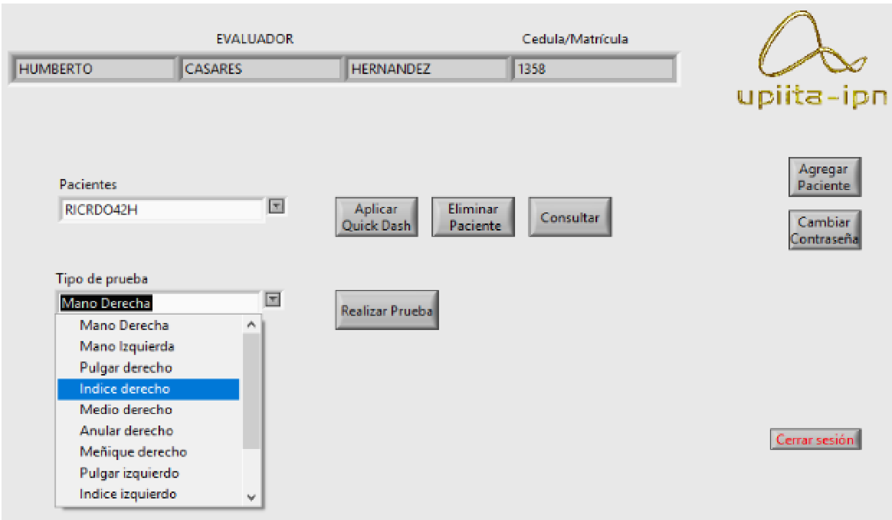

Fig. 11. Management system home screen.

in the menu, there are options to add, delete, consult, or modify patient data and change account password (see Fig. 8).

The management system for the patient data, the information from the questionnaires, and the data collected from the sensor use a database with an event-driven programming paradigm. This method consists of programs that attend events, and the functions are loaded and executed according to the selection flow. So, the program uses a menu of options and does not have a single flow of information. LabVIEW was used for the implementation of the system.

For the test module, the DAQ Assistant Object was used to measure the analog signals coming from the sensors stage. The flow diagram is shown in Fig. 9, the blue oval is the start of the program, and the red oval is the end. Each rectangle is a button and therefore has a scheduled event that could affect the database (green objects) or not.

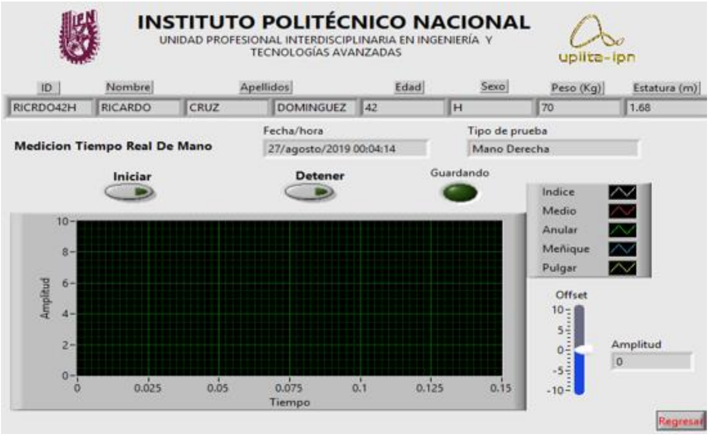

Fig. 12. Sensor dashboard.

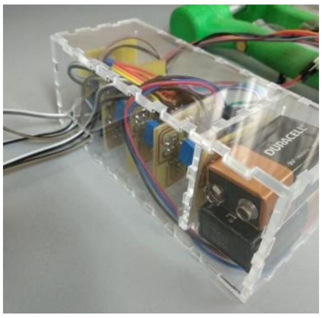

Fig. 13. System prototype version 2.

2.7 Fingerprint Database

The database implemented is shown in Fig. 10; a relational database was designed in MySQL to manipulate the information efficiently since it is a high-performance manager. It consists of 4 tables that are: evaluator, patient, test, and Qdash. These tables are used to create evaluator profiles or change their password, to add, delete, or modify patient information for their tests or Quick Dash questionnaire.

2.8 Graphical User Interface

This system considers the evaluator profile, and it can perform various functions into the patients' folder (see Fig. 11). It allows to add, delete, and consult patient information. It can also perform several tests and questionnaires for the same patient and associate them with the patient's folder.

It starts with an evaluator log in, in which he can enter or create a new account. Then, evaluator menu options are to add or remove patients, apply the digitized Quick Dash

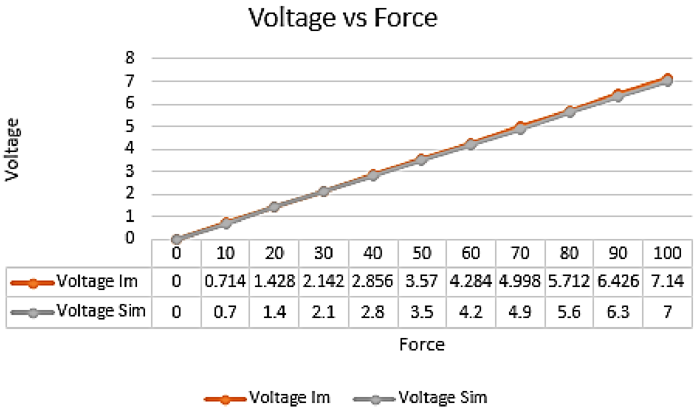

Fig. 14. Graph of voltage sensor performance against the applied force.

questionnaire, perform strength tests with real-time monitoring, and consult previously recorded results.

The tests can be of a single finger or all the fingers of a hand (see Fig. 12). The physician decides according to the diagnosis or treatment that the patient is following and his previous performance. He can reproduce previous recordings or generated new ones.

3 Results and Discussion

The sensor preprocessing stage was redesigned in a modular version, based on the one proposed by Reyes (2018). This version implements and characterizes a first-order passive low pass filter with impedance dependent amplification associated with the force sensor range with a cut-off frequency of 100 Hz [13].

The PCB boards are modular, but a case was designed to contain them in conjunction with a grip grab mechanism generated by [4].

In a clip grasp test, one PCB board was used for a single sensor. The thumb must press down; in the others, it is supported by the thumb, such as the index, middle, ring, or little finger.

In a claw grasp test, the five modular circuits are encapsulated in a box with their batteries, input, and output slots, as shown in Fig.13.

With the developed system, results have been obtained in simulation and a laboratory test of the system. The force results were accorded with the voltage obtained from the circuit, calibrating it to a voltage of 7V output for a 100kgF in the simulation and recording versions. The final maximum output voltage in the implementation was 7.14V.

The relationship between voltage and applied force was generated by the output voltage values associated with the applied force values. Therefore, the voltage values are directly proportional to the force applied to the sensor presenting linearity on the full scale of the study with an error < ±2.5% in the last part of the range of the sensor [14].

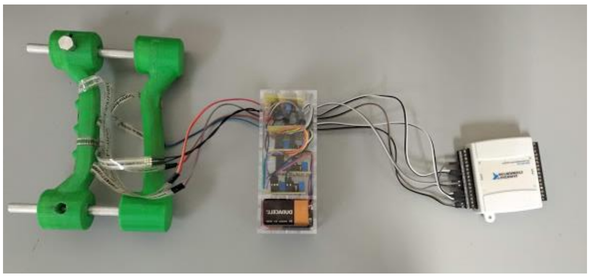

Fig. 15. Final fingerprint measurement system.

Fig. 16. A graphical user interface to consult a patient's results.

This relation of values is shown (see Fig 14), in which the results of the simulation can be observed with respect to the values of the implementation. Voltage Im belongs to the implementation, while Voltage Sim belongs to the simulation.

The event programming paradigm requires to define which event will be performed by each button and which actions are performed depending on each active window. Data flow languages like LabVIEW allow automatic parallelization of processes in programming. Unlike sequential languages like C and C++, graphical programs inherently contain information about which parts of the code they are supposed to run in parallel. The final version of the software has been tested and used in the laboratory with a no reported problem.

This system is intended for rehabilitators who can perform the force measurement and control those measurements (see Fig. 15). The hand test sensors are integrated into a device that must be pressed like a clamp; the force applied to each sensor is acquired by the software and saved in a TDMS file.

One of the project's primary purposes is to optimize the processes for the evaluators in the follow-up of the rehabilitation of the hand. Figure 16 shows the window for consulting the data of a patient. The results of the Quick Dash questionnaires are displayed as a list with date, time, and percentage in the blue box. The red box shows a graph in which files generated from the finger or hand tests can be loaded; dates/times and the force applied to the sensor in that time interval is included. The information shown here is thanks to the database; the timestamps are saved from having better feedback on the patient for the questionnaires and hand tests. This information helps the evaluator or even another evaluator to follow up on the patient for rehabilitation.

This system has similar functionality that [4, 5]proposes, but this version can be in a deployable version. The modular approach and minimum components make this system very versatile, light, and robust. This system could be used independently of the characteristics of the user and which hand is testing.

4 Conclusions

This system can be used as a monitor in the rehabilitation process of the hand, for carrying out the force tests such as grab and clip test and reduce the physician time need to manage the electronic file of each patient in a standard rehabilitation room, giving him the possibility to associate the questionnaires, and force recordings into the session report of each of his patients, with the possibility to quickly recover the previous results from the database, during the following sessions of the therapy. The use of a low-cost data acquisition board is justified because the system only needs five analog inputs to process the signals from the sensors to a computer in this version of the system.

An advantage of using a database is the scalability of adding new functions to the system. Nowadays, the database is local, and a future job could be to run it from a web server to be manipulated from various devices and even from other rooms. In that case, the administrator's role should be included and an option to eliminate the evaluator's profile while avoiding inconsistency because there could be patients without foreign keys. In this system version, deleting the profile is not considered, but a function to assign a new evaluator could be added for patients that require a new evaluator.

The use of this system in a room of rehabilitation with several physicians along a labor day, with the possibility of recovering the information for the previous session just with his session login, could increase the following up into a moving health service to e-health. This system explores a variant of the previous version reported in [4] with improvements in managing the information and integrating the processing in a single platform. Moreover, this system could be used for force tests into other protocols because of the modularity, not necessarily hand injuries. The experimental phase was not thorough in terms of the actual version. But the concept of the system was fulfilled tested in a pilot test in [4]; several technical improvements were made, and this version could be used in the clinic because it already has roles and security access.

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