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Graphical Interface for an Assistive Robotic System for Diagnosis and Rehabilitation of Elbow Tendinopathies

Jeisson Domínguez [1], Andrés Guatibonza[2], Lina Penuela[3], Alexandra Velasco[4] And Leonardo Solaque[5]

[1] Mechatronics Department, Universidad Militar Nueva Granada,
Bogotá, Colombia
u1801788@unimilitar.edu.co

[2] Mechatronics Department, Universidad Militar Nueva Granada,
Bogotá, Colombia
est.andres.guatibo@unimilitar.edu.co

[3] Mechatronics Department, Universidad Militar Nueva Granada,
Bogotá, Colombia
lina.penuela@unimilitar.edu.co

[4] Mechatronics Department, Universidad Militar Nueva Granada,
Bogotá, Colombia
alexandra.velasco@unimilitar.edu.co

[5] Mechatronics Department, Universidad Militar Nueva Granada,
Bogotá, Colombia
leonardo.solaque@unimilitar.edu.co

***Abstract*: The use of assistive robotics for physiotherapy is increasing due to their advantages, such as reducing rehabilitation times. Many topics are associated with the development of these kinds of systems. One of them is the graphical user interface, which is the way for the user (medical staff) to define tasks and evaluate information acquired by the system. Here, we present the design process of the graphical user interface for a robotic system developed for the diagnosis and rehabilitation of elbow tendinopathies. The design includes understanding the physiotherapy process to define the system specifications and restrictions, the routines, the utilities for the robotic system design, and the requirements to interact with the medical staff.**

***Keywords*:** Graphical user interface, assistive robotics, elbow tendinopathies**.**

I. Introduction

Between 1% and 3% of the total population experience elbow tendinopathies during their productive years, usually between the ages of 30 and 55 [1]. This type of injury results from repetitive wrist extension and forearm supination movements, causing micro-ruptures of the tendons and muscles in the epicondyle region [2]. The risk of suffering this kind of tendinopathies increases with aging. Another risk factor is the job performed; where there is more incidence among tennis players, butchers, chefs, mechanics, and building workers [3]. The main problems related to these injuries are pain and functional incapacity, as difficulties in performing daily activities [1]. Diagnosis is held by a physician through palpation, evaluation of pain, range of movements, and muscular weakness. On the other hand, rehabilitation seeks to recover the range of motion, strength, and functionality, avoiding incapacities or surgeries [4, 5]. Nevertheless, some of the problems associated with rehabilitation are the pain perceived during the rehabilitation exercises that cause difficulties in performance, and musculoskeletal disorders for therapists caused by repetitive movements with high loads [6].

Assistive robotics are becoming an alternative to support physical rehabilitation and diagnosis [7, 8]. The use of these technologies has been increasing in recent years due to the ease of generating therapy trajectories and adaptation to rehabilitation schemes according to the patient's needs, in addition to allowing the quantification of evaluation variables such as joint mobility, joint velocity, muscle activity and strength. [9, 10].

Considering the design of systems for assistive rehabilitation, diagnosis, and monitoring, one of the areas of great interest is the system-machine graphical interface which allows users to define the actions and tasks of the assistive system, access evaluation information and monitor system variables.

The design and use of graphical user interfaces (GUI) play a key role in the field of robotic systems. These interfaces provide an intuitive and efficient way to interact with robots, allowing users to control and monitor the tasks performed by these systems. A well-designed graphical interface can improve usability, productivity and safety when working with robots by facilitating programming, monitoring and data visualization. Graphical user interfaces should be designed with the needs and abilities of the end users in mind. The interface should be intuitive, with a clear layout of controls and an understandable visual presentation [14]. In addition, it is important to consider the adaptability of the interface for different tasks and work contexts, as well as the ability to provide visual feedback and assistance during interaction with the robotic system.

The design of graphical interfaces for robotic systems has been the subject of several research. These works have addressed various aspects, from social interaction with robots to industrial collaboration and cooperative manipulation. In the literature, graphical interface designs for robotic systems have been proposed, highlighting the importance of considering factors such as workflow, social interaction, industrial collaboration and cognition distribution. These works have provided approaches, methodologies, and practical considerations for the design of graphical interfaces that improve the usability and efficiency of human-robot interaction in various contexts. For example, in [15], the authors show the importance of friendly user and real-time feedback interfaces that seek a simpler and more organic interaction with the user. Similarly, in [11], a 6 DoF robot called NJIT-RAVR (New Jersey Institute of Technology Robot-Assisted Virtual Rehabilitation System) has been proposed for physical upper limb rehabilitation, where virtual reality is supported with a comprehensive graphical interface to support therapy process. Or in [12], where a system named D-SEMUL for upper limb rehabilitation has been proposed. In this work, the usability of the user interface and the affinity of the training program, the acceptability of the design, the touch screen and the background music in affinity with the graphical interface are evaluated for experience performance.

On the other hand, in the work of [28], the factors influencing human-robot interaction in organizational environments were investigated. The effects of workflow, social and environmental factors on robot interaction were examined, providing a basis for the design of graphical interfaces that take these aspects into consideration. Additionally, in [29] the authors focused on the design of graphical interfaces for collaborative robots in industrial environments. Their research focused on developing intuitive and efficient interfaces that would allow human operators to control and monitor tasks performed by robots, thus improving productivity and safety in human-robot collaboration. Also, in [30] the authors focused on the design of graphical interfaces for robot operators in cooperative manipulation tasks. They investigated how to effectively present relevant information, such as position and force, to improve coordination and communication between human and robot operators in collaborative work environments. Similarly, in [31] explored the social interaction between humans and robots through a group percussion scenario. Their work focused on designing a graphical interface to facilitate human-robot collaboration in a musical activity, integrating visual and auditory elements for seamless and natural interaction. Finally, in [31] adopted a distributed cognition perspective for the design of human-robot systems in complex and dynamic tasks. The authors proposed a situated cognitive engineering approach, which consider the distribution of cognition between humans and robots, to develop graphical interfaces that enhance mutual understanding and coordination in challenging situations.

The use of graphical interfaces in robotic rehabilitation systems plays a crucial role in improving the efficiency and user experience during the rehabilitation process. Research and development of new graphical interfaces for rehabilitation robots can improve the effectiveness of treatments by optimizing exercises and adapting therapies to the individual needs of each patient. Sharing knowledge about best practices in the design of rehabilitation-specific graphical interfaces would help to establish standards and guidelines for future developments and improvements, and foster collaboration in the field of robotic rehabilitation.

In this paper, we present the graphical user interface design for a robotic assistive system for the diagnosis, rehabilitation, and assessment of patients with elbow tendinopathies. We present some methodological aspects to determine the characteristics of the robotic system, as well as the block diagrams of the general system as a basis for determining the design properties of the graphical user interface. Afterward, we explain the methodology to develop the GUI, and then, we present the results obtained as screenshots of the final GUI.

II. Methodology

In this section, we present the general design criteria for a 7-DOF robotic system designed for the diagnosis, rehabilitation, and assessment of elbow tendinopathies. We define the design characteristics of the graphical user interface based on the system design, considering clinical recommendations.

A. Robot design characteristics definition

The design of the robotic system starts with the comprehension of the elbow joint biomechanics, the tendinopathies' diagnosis, and rehabilitation processes. Here we describe the upper limb anatomy, the exercises for diagnosis and rehabilitation, the requirements and specifications, and a description of the system design.

1) Upper limb anatomy

The upper limb is composed of three parts: arm, forearm, and hand. The shoulder is the joint where the ends of the humerus, the scapula, and the clavicle bones merge. The shoulder is the most mobile joint in the entire body, since it allows the orientation of the upper extremity in the three anatomical planes (sagittal, frontal, and transverse), thus allowing the movements of flexion-extension, adduction-abduction, internal-external rotation, and flexion-horizontal extension. This is possible through the subdeltoid, acromioclavicular, scapuloscapular, sternocostoclavicular, and scapulohumeral. The muscles linked to the humerus are the triceps and biceps that perform the movements produced from the shoulder. Between the arm and the forearm, we find the elbow joint, where the humerus articulates with the ulnar and the radius. The elbow is the middle joint of the upper extremity. It allows the movements of flexion and extension (humerus-ulna), distributes the load forces (humerus-radius), and transmits the motions of pronation and supination (cubitus-radius) to the

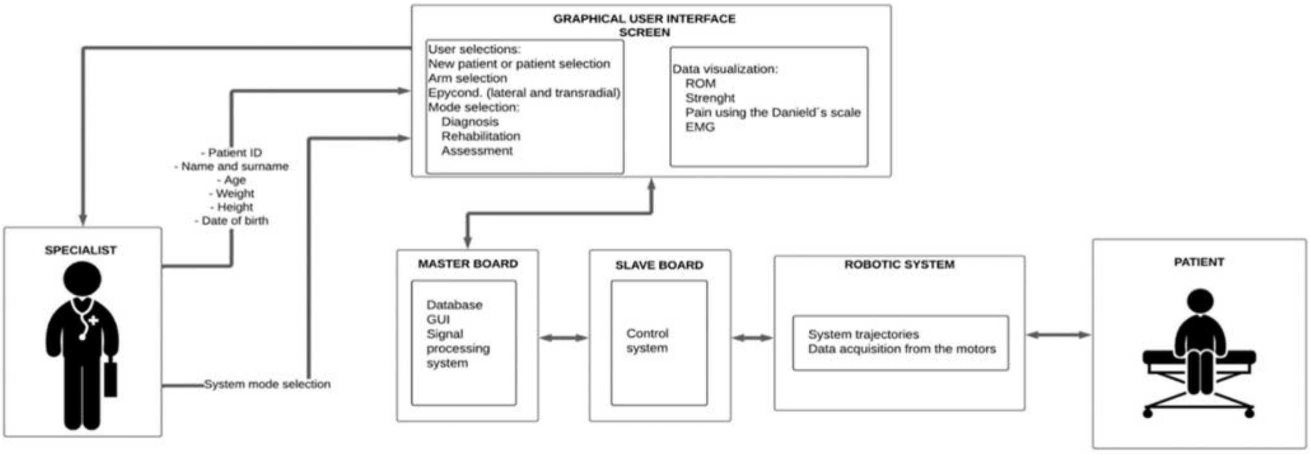


Figure 1. General system’s block diagram

wrist. The forearm is composed of two bones: the ulna and the radius, which are attached proximally to the humerus through the elbow, and distally to the carpals through the wrist. Due to the structure of the ulna, it does not perform rotary movements. However, unlike the latter, the radius can rotate around a longitudinal axis, transmitting the rotation movement to the hand, known as pronation and supination motions. Finally, the hand corresponds to the lower part of the extremity, located at the end of the forearm. It goes from the wrist to the fingertips. The hand has four parts; i.e., the carpus, the metacarpus, the palm, and the phalanges [16, 17]. Table 1 shows the ranges of motion, considering each joint and the kind of movements performed.

Table 1. Joints and range of movements [16].

Joint	Movement	Range [°]
Shoulder	Abduction	0-180
	Adduction	0
	Flexion	0-180
	Extension	0-60
	Internal rotation	0-70
	External rotation	0-90
	Horizontal flexion	0-135
	Horizontal extension	0-40/50
Elbow	Flexion	0-150
	Extension	145-0
	Pronation	0-90
	Supination	0-90
Wrist	Flexion	0-80
	Extension	0-70
	Pronation	0-80
	Supination	0-80

2) *Tendinopathies and physiotherapy*

Some of the traumas related to the elbow are fractures, dislocations, and sprains. Elbow tendinopathies are also very common; these can be at the epicondyle (epicondylitis) or the epitrochlea (epitrochleitis). This often occurs in people who play sports such as tennis or golf, or home or work activities that require constant use of the joint and repetitive movement. These elbow tendinopathies cause inflammation of the tendinous structures that attach from the muscles to the bony structures. In the case of epicondylitis (tennis elbow), caused by repetitive movements that produce pain in the lateral elbow near the lateral epicondyle at the origin of the wrist extensor muscles. On the other hand, in the epitrochleitis (golfer's elbow) the pain is perceived on the inner side and is caused by an overload of the flexor and pronator muscles that affects the tendinous insertion in the epitrochlea of the elbow due to hyperflexion movements [17].

In all cases, a physical rehabilitation process is required to restore the person socially, physically, and professionally after suffering any condition [6, 18]. Within physical therapy, the therapist uses some tests to validate the diagnosis of tendinopathy. Once the injury is diagnosed, rehabilitation exercises begin [19]. For the development of the robotic system to assist diagnosis and rehabilitation, we selected the exercises shown in Tables 2 and 3, according to the literature review and the definitions of the system requirements, determined by the medical staff.

Table 2. Diagnosis test [16].

Epic. class.	Test name	Joint	Exercise
Lateral	Maudsley	Wrist and elbow	Middle finger extension and application of opposite force, with the elbow extended.
	Mills	Wrist and elbow	Wrist flexion with ulnar deviation, and progressive elbow extension
	Thompson	Wrist	Closed hand extension, and application of opposite force
	Cozen	Wrist	Closed hand extension with elbow set at 90°, and application of opposite force.
Medial	Test 1	Wrist	Wrist flexion with elbow fixed, and application of opposite force.
	Test 2	Wrist	Passive dorso-flexion
	Cozen inverted	Wrist	Wrist flexion with hand extended in supination, and application of opposite force.
	Golfer´s elbow sign	Wrist and elbow	Extension of the arm with palmar flexion of the wrist, and application of opposite force.
	Forearm extension	Elbow	Extension of the arm leaving the forearm in supination, and application of opposite force.

The rehabilitation process considers three main phases: the first one intends to recover the joint´s flexibility, the second phase is for the recovery of the joint´s range of motion, and the last one is to increase the strength.

B. Robotic system tasks definition

The system is designed for different types of assistance. First, passive assistance mode, where the robot assists the process using the activation of its actuators during the exercises. Second, active-assisted; the robot partially assists the process. Third, isotonic mode; the robot in this mode does not interfere with the movements. Fourth, isometric mode, in which the robot provides a static muscular level contraction. Finally, resistive mode, in which the robot assists dynamic muscle strengthening [21, 22, 23] (see Figure 1). The assistance modes limit the parameterization of the exercises based on the patient's evaluation and monitoring. Therefore, during the recovery of flexibility, the system provides the user with the necessary assistance to perform the exercises. In this case, the system provides passive assistance. During the therapies for recovery of range of motion, the active-assist mode decreases, and the patient performs the activity. Therefore, the system is activated when the patient cannot reach the required position. In the case of isotonic exercises, the robotic system applies an opposing load to the user when the user performs the activity with changes in the position. On the other hand, when the goal is to increase strength, isometric exercises are like isotonic exercises, but there is no change in the position. Finally, in the resistive mode, the robotic system exerts a load at different levels according to the patient's needs [16, 24, 25, 26]. The last assistance levels are related to the control techniques that modify torque, position, or velocity.

Table 3. Rehabilitation exercises [16].

Epic. class.	Joint	Exercise
Lateral	Wrist and elbow	Stretch wrist extensors and flexors, pronation-supination of the forearm, and flexion-extension of the wrist
	Wrist, shoulder, and elbow	Stretching of wrist flexors and extensors, forearm pronation-supination, wrist flexion-extension, and grip.
	Wrist, shoulder, and elbow	Wrist extensor and flexor stretches, forearm pronation-supination, wrist flexion-extension, grip, and isometric exercises.
Medial	Wrist and shoulder	Stretching of the extensors and flexors of the wrist, pronation-supination of the forearm, flexion-extension of the wrist

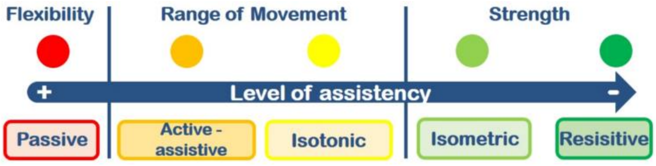


Figure 2. Levels of assistance according to the proposed phase of recovery

The system architecture considers the different processes needed to meet the medical and engineering requirements. In the following, we define these requirements.

Medical and therapeutical requirements:

- Mode selection:
    - Diagnosis
    - Rehabilitation
    - Assessment
- Exercises for diagnosis (see Table 2).
- Exercises for rehabilitation are associated with the level of assistance (see Table 3 and Figure 1).
- Torque and angular position for each degree of freedom according to the anatomy and the procedure required for the patient.
- Data to be visualized and saved:
    - ROM
    - Pain level
    - Strength

Engineering requirements:

- Mechanical requirements:
    - Degrees of freedom: 7DOF
    - Mechanical structure
    - Stability
    - Weight
    - Structure and materials resistance
    - Type of movements to perform
    - Transmission mechanism
    - Maximum deformation allowed
- Definition of the robotic arm trajectories.
- Control of angular position and torque
- Drivers and power required by the motors and the system
- Signal acquisition and processing
- Database
- GUI
- Security for the users: personal data, stop buttons, and emergency stop.

In this way, we have defined the system block diagram (see Figure 2), where there are two boards to execute the tasks. The mainboard oversees the database, the GUI and the signal processing for the EMG signal, and the development of patients' monitoring reports. Depending on the user's selection on the GUI, the mainboard sends the information to the slave board which oversees the control system to define trajectories, velocities, and torques for the motors integrated into the robotic structure. At the same time, the motors provide the required information to calculate variables such as ROM and strength.

C. Graphical user-interface design and Specifications of the GUI

To develop a GUI for users in medicine, there are some general characteristics to meet, according to [14, 22, 23]. These characteristics are listed as follows:

- Incorporation of medical symbols
- Preferred screen characteristics like color, icon location, etc.
- Friendly interaction

- Ease of use
- Real-time data visualization

Additionally, the graphical user interface is designed considering the available variables that can be accessed from the system, as well as the defined diagnostic and rehabilitation schemes, emergency buttons, system use tutorials, and data display and storage. Based on the aspects determined in the block system of the Figure 1, the order and information of the interface screens is established.

Figure 3 shows an example of the flowchart developed for the selection of a patient already created or the creation of a new patient. In this part, the user has the possibility to load the data of an old patient or create a new one by directing the user to another screen where the new patient's information such as name, ID, age, affected arm, weight and height is entered. This information is saved into the database. Furthermore, the system creates a record for the user and calculates the body mass index. This is basic information that is usually obtained in a typical therapy. Once the new patient is created or is selected from the database, the GUI displays the arm selection.

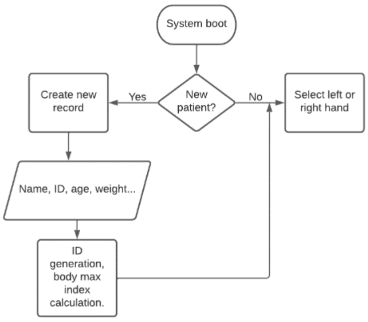


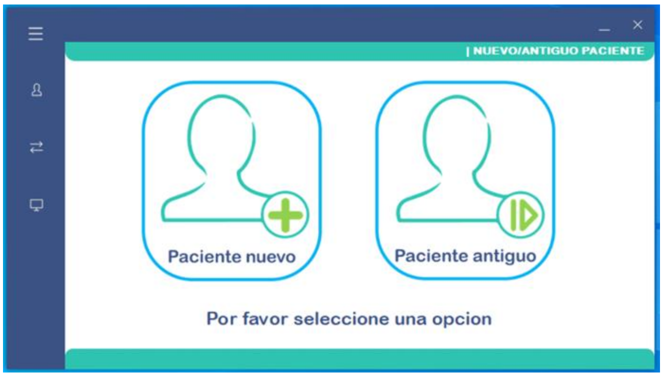
Figure 3. Flowchart of new record creation.

Once the specifications and characteristics of the system and the GUI were defined, we implemented the interface in Python, using libraries such as Tkinter for an early stage and PyQt5 for the final version. We implemented the GUI in a Raspberry Pi 4 (Master Board) and displayed it in a 7-inch LCD touchscreen display of 800x480 pixels.

III. Results

For the data collection, we have proposed a redundant 7 DoF upper limb robotic system. The system allows to perform protraction - retraction (scapulohumeral), horizontal flexion-extension (glenohumeral), flexion-extension (glenohumeral), adduction - abduction (glenohumeral), elbow flexion-extension, wrist pronation - supination, and wrist flexion-extension. The data collection is obtained from the motors, including joint angular positions and velocities, and joint torques. The robotic system structure is shown in Figure 4.

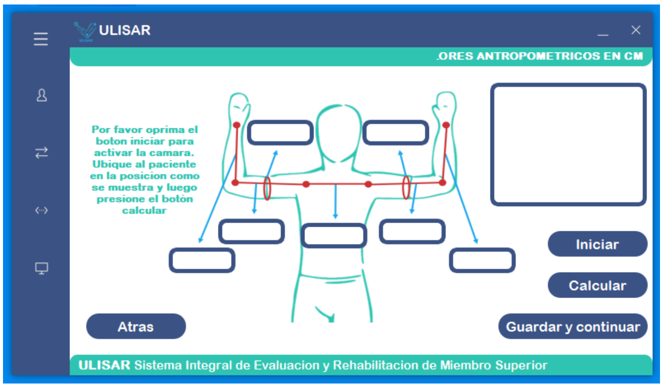
Figure 4. Assistive robotic device.



Por favor seleccione una opcion

Figure 5a. Old/New patient selection design.

Figure 5b. New patient creation section.



Por favor oprima el boton iniciar para activar la camara. Ubique al paciente en la posicion como se muestra y luego presione el botón calcular

Figure 5c. Anthropometric estimation system.

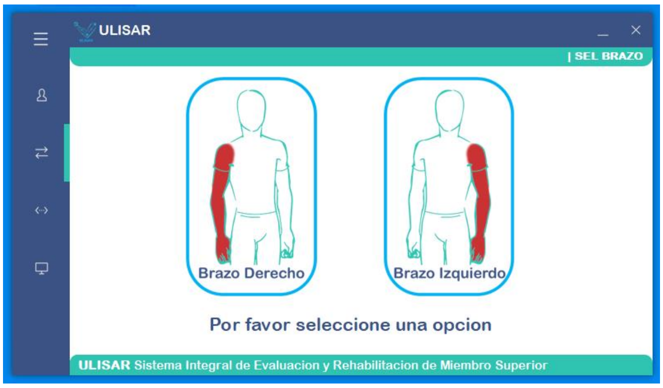


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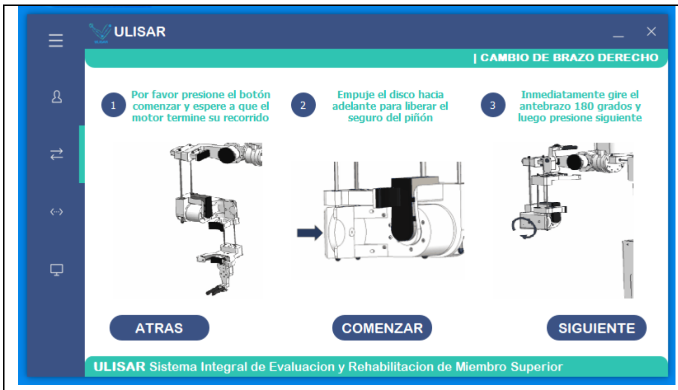
Figure 5d. Arm selection section.

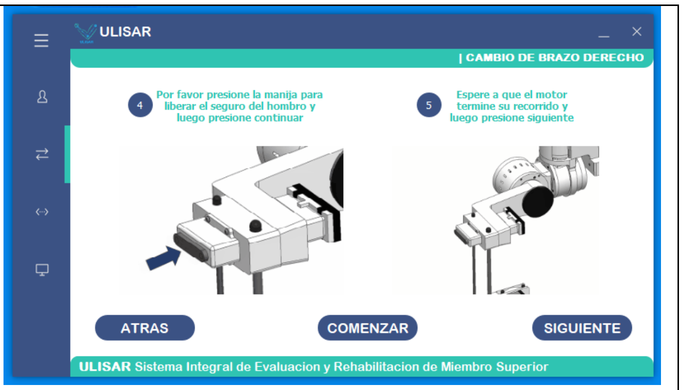


1 Por favor presione el botón comenzar y espere a que el motor termine su recorrido

2 Empuje el disco hacia adelante para liberar el seguro del piñón

3 Inmediatamente gire el antebrazo 180 grados y luego presione siguiente

Figure 5e. Instructions for left or right arm configuration: elbow joint displacement



4 Por favor presione la manija para liberar el seguro del hombro y luego presione continuar

5 Espere a que el motor termine su recorrido y luego presione siguiente

Figure 5f. Instructions for left or right arm configuration: Shoulder joint displacement

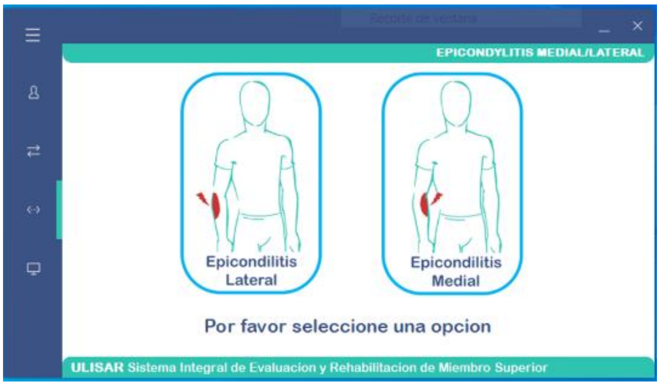


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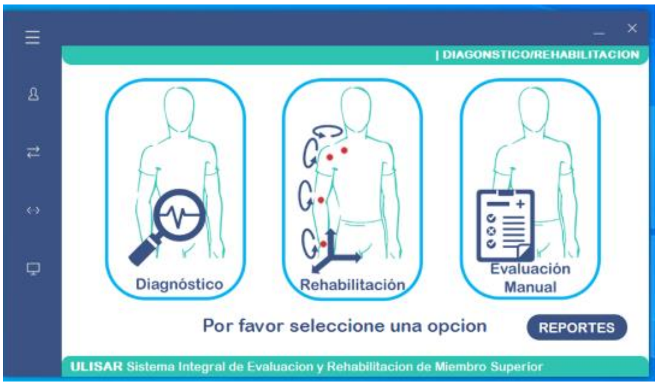
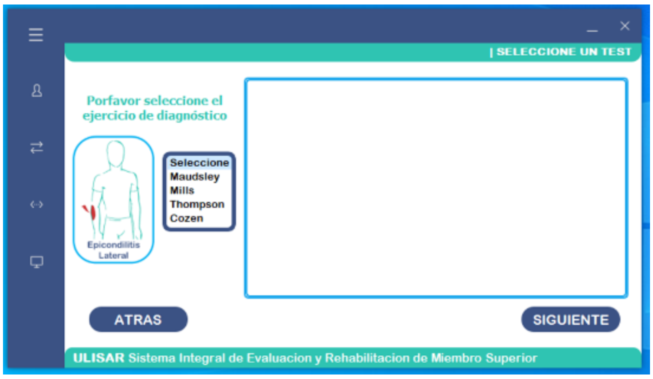
Figure 5g. Epicondylitis type selection.



Por favor seleccione una opcion

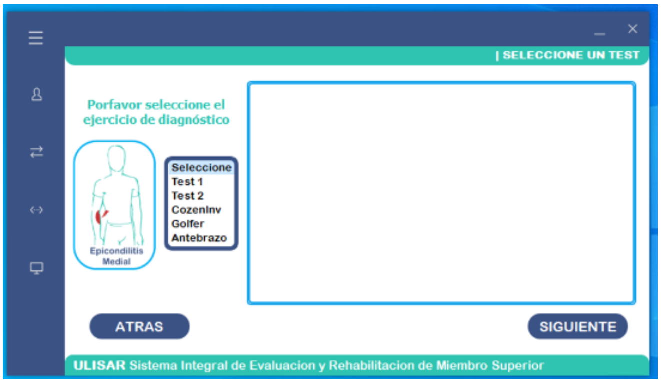
Figure 5h. Diagnosis, rehabilitation or manual evaluation selection.



Porfavor seleccione el ejercicio de diagnóstico

Seleccione
Maudsley
Mills
Thompson
Cozen

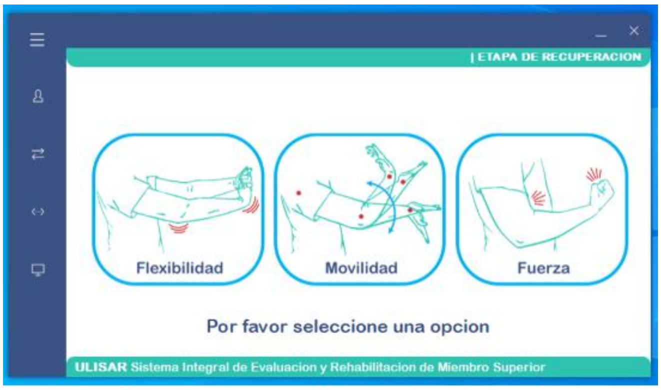
Figure 5i. Diagnosis for lateral epicondylitis.



Porfavor seleccione el ejercicio de diagnóstico

Seleccione
Test 1
Test 2
CozenInv
Golfer
Antebrazo

Figure 5j. Diagnosis for medial epicondylitis.



Por favor seleccione una opcion

Figure 5k. Rehabilitation options.

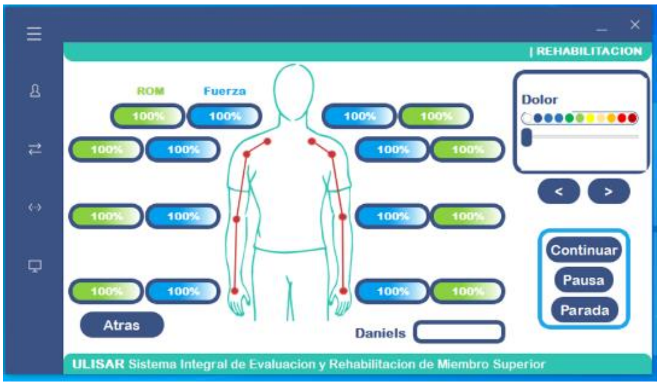


Figure 5l. Assessment report.

Figure 5. General GUI design for upper limb rehabilitation system

The graphical interface is developed in Spanish, which is the native language of the medical staff that is going to use the system in its first version. For the graphical interface, we selected some characteristics such as colors, typography, and to a greater extent, the use of illustrative images for easy understanding. All images and sketches were designed using Adobe Illustrator. The idea was to implement an intuitive and friendly GUI that would also guide the user in manipulating the system. Some of the screens are shown in Figure 5.

Figure 5a shows the entry of a new patient into the database or the selection of a created patient. When the user selects *New Patient*, the system asks for information such as name, surname, gender, age, height, weight, and the arm to be diagnosed or rehabilitee. With this information, the system calculates the body mass index and creates the patient´s ID (see Figure 5b). When the user selects “Save and continue” (*Guardar y continuar*), the GUI displays Figure 5c, where an anthropometric estimation is performed from an image capture of the patient using neural networks, to determine the patient's anthropometrics in order to configure the lengths in the robotic system to adapt to human lenghts. This calculation is performed from a pre-trained neural network system based on microsoft's COCO dataset for pose estimation, when the picture is taken, the anthropometric dimensions are calculated in pixels and then converted to cm, these values are saved for the current patient, the measurement can be performed several times if considered, and the values are overwritten.

Consequently, after the user selects the arm, an animation is displayed with instructions for the medical specialist to manipulate the robotic system (see Figures 5e and 5f), animations describe how to configure the robot for left or right arm depending on user's choice. Afterward, the GUI displays the screen to ask the type of epicondylitis (medial or lateral) (see Figure 5g), depending on the selection, the diagnosis and rehabilitation schemes of the pathology are loaded to allow further selection between diagnosis, rehabilitation, or manual evaluation (see Figure 5h). According to Table 2 and Table 3, the system displays the options for medial and lateral epicondylitis diagnosis (see Figures 5i and 5j), when making a selection in each exercise, the animation of how it should be executed is displayed.

Then, when the assessment option is selected, the robotic system performs trajectories to evaluate aspects such as strength and range of movement (ROM), based on measurements given by the system’s actuators and electromyography sensors. As well, the specialist can save the information of the pain perceived by the patient based on the Visual Analog Scale. Figure 5l shows the output of the system to inform ROM (green) and strength (blue), this interface allows to pause, cancel or continue the current routine, after the routine is finished, a general report is generated with the current patient data through the generated ID. In the future, the idea is to integrate the Daniels’ pain scale [27] based on a computational assessment of pain using the electrophysiological signal analysis.

The database was programmed on MySQL, a database management system developed by Oracle Corporation. The patient’s data and the information collected from the sensors are stored and processed to be visualized by the specialist and to create reports on the patient’s progress.

9. CONCLUSIONS

In this work, we presented a graphical user interface design for a robotic system that supports the process of diagnosis, rehabilitation, and assessment for elbow tendinopathies. The design process starts with the analysis and understanding of the biomechanics, and the procedures for diagnosis and rehabilitation. The methodology included integrated work with physiatrists who are the final users of the system. The database was programmed on MySQL, and it stores the patient's data and the information collected from the sensors and processed to be visualized and to create reports on the patient's progress.

This work discusses the importance of designing graphical interfaces for robotic systems that are intuitive, efficient, and adaptable to different tasks and work contexts. The interface is designed with the needs and abilities of the end-users in mind, and provides visual feedback and assistance during interaction with the robotic system. The graphical interface developed in this project is in Spanish, which is the native language of the medical staff that is going to use the system in its first version. The interface is designed to be intuitive and friendly, with the use of illustrative images for easy understanding.

Overall, this document provides valuable insights into the design of graphical interfaces for robotic systems, highlighting the importance of considering factors such as social interaction and cognition distribution. The desing also emphasizes the need to incorporate medical symbols, preferred screen characteristics, friendly interaction, ease of use, and real-time data visualization for its use with robotic systems.

Future work will include a survey to evaluate the interface by a group of health specialists, the integration of the GUI to the robotic system, and the inclusion of virtual reality in the characteristics of the prototype.

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Author Biographies

Jeisson Domínguez Is Mechatronic Engineer from Militar Nueva Granada University – Colombia. He worked as a research assistant at Militar Nueva Granada University. His main research areas are robotics, human-machine interfaces, and the design of mechatronic systems. He was a research assistant at Militar Nueva Granada University, Bogotá, Colombia.

Andrés Guatibonza Is Mechatronic Engineer from Militar Nueva Granada University – Colombia. He worked as a research assistant at Militar Nueva Granada University. His main research areas are robotics, mechanical design, and the design of mechatronic systems. He is currently a graduate assistant and Doctoral student at Militar Nueva Granada University, Bogotá, Colombia.

Lina Peñuela Is Electronic Engineer with a Master's in Electronics engineering and computing from Los Andres University - Colombia. Her main research areas are electronics, sensors, and biomedical systems. She is currently an assistant professor in the Mechatronics Department at Militar Nueva Granada University, Bogotá, Colombia.

Alexandra Velasco Is Electronic Engineer with a Master´s in Electronics Engineering from Javeriana University. She obtained her Ph.D. in Robotics, Automation, and Bioengineering in 2015 from Pisa University. Her main research areas are in Control and Robotics focused on rehabilitation systems, trajectory planning, and optimization. She is currently an assistant professor in the Mechatronics Department at Militar Nueva Granada University, Bogotá, Colombia.

Leonardo Solaque Is an Electronic Engineer from the University of Antioquia – Colombia. He studied a Master's in Electrical engineering at Los Andes University - Colombia. He obtained his Ph.D. in Automatic Control in 2007 from LAAS-CNRS and INSA of Toulouse - France. His main research areas are in control system, robotics, path planning, filter system, and sensory fusion. He is currently an associate professor in the Mechatronics Department at Militar Nueva Granada University, Bogotá, Colombia.